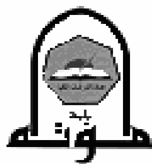


Mu'tah University

Deanship of the Graduate Studies

Electrical and Optical Properties of Selenium and Vanadium Pentoxide Thin Films

By
Osamah Mohammad Salman Al-Kasassbeh

Supervised by
Prof. Dr. Nehad Mohammad Tashtoush

A Thesis Submitted to the Deanship of The Graduate Studies In Partial Fulfillment of The Requirements For The Degree of Master of Science In Physical Department of Physics.

Mu'tah University , 2010

Acknowledgment

Thanks to my university (Mu'tah University) to Science College to Physics Department in Mu'tah University , thanks to my supervisor (Prof. Nehad Tashtoush) for his effort, support, instruction and encouragement. To all my friends in Mu'tah university a lot of thanks .

Osamah Mohammad AL-Kasassbeh

Table of Contents

List of Figures

List of Tables

Abstract

Electrical and Optical Properties of Selenium and Vanadium Pentoxide Thin Films.

Osamah Mohammad AL-Kasassbeh
Mu'tah University, 2010.

V_2O_5 and Se thin films on glass substrate were prepared under vacuum by using thermal evaporation technique using molybdenum boats . The films were deposited with different thicknesses. Deposition rate was controlled by using quartz monitor connected with the system and the rate was 5nm per thickness. The optical constants (Thickness, Refractive indices, Absorption coefficients, Extinction coefficients and energy gaps) were determined from measuring the reflectivity and transmissivity for the films using spectrometer in the spectral range 300 to 900 nm, the energy gaps were determined for all films and found that for Se films the energy gap was about 1.8 eV and for V_2O_5 about 2 eV. The electrical properties for the films were determined by the direct measuring of the sheet resistance of the prepared samples using a digital Kiethly electrometer and found that the electrical conductivity was increasing with decreasing film thickness for all films. And then we have studied the effect of temperature on conductivity and it shows that for all film the electrical conductivity was increasing with increasing temperature. Finally, the activation energy for films was determined where it was about 0.78 eV for Se films and about 0.4 eV for V_2O_5 films. All films have amorphous structure as obtained from XRD technique.
Finally. films with height absorption have height electrical conductivity.

الملخص

الخواص الكهربائية والبصرية لأفلام السيلينيوم وأفلام أكسيد الفناديوم الرقيقة

أسامه محمد الكساسبه

جامعة مؤتة, 2010

لقد تمت دراسة الخواص البصرية والخواص الكهربائية لأفلام رقيقة مصنوعة من أكسيد الفناديوم ومادة السيلينيوم المبخرة على الزجاج.وذلك باستخدام طريقة التبخير الحراري من بوتقة مصنوعة من مادة الموليبدينيوم. حيث تم تحضير عدة عينات من كلا المادتين بأسماك مختلفة, وتمت السيطرة على معدل التبخير بواسطة شاشه من الكوارتز موصولة بنظام التبخير. بحيث تم تثبيت المعدل ليكون بحوالي 5نم للسمك الواحد. الخواص البصرية مثل (السمك, معامل الانكسار, معامل الامتصاص و معامل الانطفاء) حددت من خلال قياس النفاذية والانعكاسية للأفلام باستخدام مقياس طيفي في المدى من 300 إلى 900 نانوميتر. الخواص الكهربائية حددت من القياس المباشر لمقاومة الأفلام حيث وجد انه كلما قلت سماكة الأفلام زادت موصليتها. كذلك تمت دراسة أثر زيادة درجة الحرارة للأفلام على موصليتها الكهربائية فوجد أنه مع زيادة درجة الحرارة للأفلام تزداد موصليتها, ثم تم إيجاد طاقة الحفز للأفلام فوجدت 0.78eV لأفلام السيلينيوم و0.4 eV لأفلام الفاناديوم. جميع القياسات تمت للعينات بعد التبخير مباشرة حيث استخدمت تقنية الXRD والتي بينت أن الأفلام بحاله غير متبلورة .

وتم الربط بين الخصائص البصرية والكهربائية فوجد أن الأفلام ذات الامتصاص العالي لها قدره أكبر على التوصيل الكهربائي .

Chapter One
Introduction

Semi-conducting materials were considered to be of high importance and interest in the physics society. This is due to their wide and vital use in electrical devices and microelectronics. Their physical properties, structural, electrical and optical, enhanced and speed up the technical industry. Developing their methods of preparation especially in the thin film or layer form gave rise to a very wide applications. Now, there is much current interest in all semi-conducting materials and their compounds for use in a variety of solid state devices.

Thin films of semi-conducting materials generally have neither the same physical properties nor the same chemistry as the respective bulk material. Moreover, the preparations techniques and deposition processes that used to create films (thin or thick), far away from thermodynamics and high surface to volume ratio, dramatically change the physical properties of material such as refractive index, extinction coefficient, homogeneity, density, hardness, internal stress, adhesion to substrate, and crystal structure. Therefore, the difference in physical properties between bulk and thin film material depends strongly on many factors such as the type of deposition process itself, deposition temperature, deposition rate, gas pressure, substrate geometry, preparation of the coating material and the post-deposition temperature.

Since thin films of materials, rather than bulk, can be easily integrated with microelectronics industry and nanotechnology, they open completely new areas of applications in almost all field of science and technology. Thin films are thin material layers ranging from fractions of a nanometer, monolayer, to several micrometers in thickness. Electrical semiconductor devices and optical coatings are the main field of applications benefiting thin film construction, some of which are:

1. Solar cell fabrication
2. Chemical gas sensors
3. Switching devises
4. Radiation detectors
5. Li – Solid state batteries
6. Photovoltaic cell
7. Optical devices

1.1 Thin Film Preparation Techniques

Studying the structural, electrical, and optical properties of thin materials is a big concern. Therefore, processes and techniques of preparing thin films grow dramatically. Scientists found and report many methods for thin film preparation, these techniques fall into two broad categories depending on whether the process is primarily chemical or physical. These categories can be summarized in the following:

1.1.1 Chemical Deposition Techniques

In this technique, a fluid precursor undergoes a chemical change at a solid surface, leaving a solid layer (thin film). This can be achieved by one of the following chemical deposition [1,2,5]processes:

1. Plating .
2. Chemical solution deposition (CSD)
3. Chemical vapor deposition (CVD)

1.1.2 Physical Deposition Techniques

Physical deposition uses mechanical or thermodynamic means to produce a thin film of solid. This can be done using many different techniques, that are [1,2]:

1. Sputtering
2. Pulsed laser deposition
3. Cathodic arc deposition
4. Electron beam evaporator
5. Ion beam
5. Sol – gel method
6. Thermal evaporation

In our study we will use the last technique, i.e. the thermal evaporation, in which an electric resistance heater (Mo boat) was used to melt the material and rise its vapor pressure to a useful range, this is done in a high vacuum. both allow the vapor to reach the substrate without reacting with or scattering against other gas – phase atoms in the chamber and reduce the incorporation of impurities from the residual gas in the vacuum chamber. Obviously, only materials with a much higher vapor pressure than the heating element can be deposited without contamination of the film. This technique has been most extensively developed, and it possesses many advantages over the other methods such as:

1. It produces film of high purity

2. It has a minimum of interfering conditions
3. Inexpensive method
4. Produce a homogeneous films with a stoichiometric composition

1.2 Optical Properties of Amorphous Semiconductors

In general, when a light passes through a material its speed will change. The magnitude of change depends on the optical properties of the two optical media. The most important optical constant that can be used to describe the behavior of light through transparent materials are:

1. The refractive index, n
2. The absorption coefficient, α

The refractive index of an optical material or dielectric medium is generally defined as the ratio of the speed of light in vacuum, c, to its speed in the material, v. In general, the refractive index, **n**, is a complex quantity which is given by:

$$\mathbf{n} = n - ik \qquad \text{---1.1}$$

in which, the real part of this complex refractive index, n, is the refractive index while the imaginary part, k, is the extinction coefficient which is a measure of energy loss and related to the absorption coefficient, α, according to the relation:

$$k = \frac{\alpha\lambda}{4\pi} \qquad \text{---1.2}$$

where λ is the wavelength of the incident light [3,4].

The importance of the absorption coefficient is that it indicates how readily photons will be absorbed by the material. The absorption coefficient, α, decreases with increasing energy gap for each particular photon energy [5].

Measuring the refractive index and the absorption coefficient is of a great importance for any semi-conducting compound that will be used in any application especially that related to optical applications. To do so, some experimental measurements and data must be known and taken. This can be done by many ways, some of which is to measure the reflectance, R, and transmittance, T, for the film; other one based on the ability of the film to form an interference pattern, and then using what is referred to as the envelope method [4].

In our study, we will use both methods to measure the optical constants of two compounds; the first, is the amorphous Selenium, *a-Se*, and the second

is the Vanadium Pent-oxide, V_2O_5. these two compounds were chosen for their wide range of applications in many fields especially sensing, solar cells, and others.
Therefore, we will report upon the optical and electrical properties of *a-Se* thin films prepared by thermal evaporation under vacuum. Moreover, we will report about the optical and electrical properties of V_2O_5.

In the next few sections a brief history of the electrical and optical properties of our systems will be given.

In the second chapter, a theoretical background of the method of calculations of the optical and electrical constants are given. Also, the method of calculating the film thickness, which is one of the major problems in thin film studies, is reviewed.

The third chapter is devoted to the experimental detail related to the entire work in this study. It involves a description of the thin film preparation tools, and the optical and electrical instruments used in our measurements.
The fourth chapter contains the results and discussion for the optical and electrical properties of the a-Se and V2O5. Moreover, the conclusions and the recommendations for future work will be given.

1.3 Electrical and optical properties of *a-Se*

Selenium is a nonmetallic (semiconductor) chemical element with an atomic number 34 and an atomic mass of 78.96 g. Its melting point is 494 k and its boiling point is 958 k. It is represented by the symbol Se and rarely occurs in it's elemental state in nature. Selenium occurs in several different forms, the most stable of which is a dense purplish – gray semi metal (semiconductor) form that is structurally a trigonal polymer chain. It conducts electricity better in the light than in the dark, therefore it is widely used in photocells.

Most, if not all, of the electrical and optical properties of *a-Se* thin films have been investigated . However, we will try to reintroduce some of these in our Lab in order to follow up with a new study about the electrical and optical properties of some of its alloys which is composed of *Se* and *In* and *Bi* in the form of Se_xY_{1-x}, $Y = In$ or *Bi*.

The room-temperature ac conductivity and the real part of the dielectric constant of amorphous selenium was investigated [6]. it was found that the thermally activated hopping was the most likely process. The two-photon photo-generation was observed by R. C. Enck [7]. Moreover, the influence of wavelength on the optical quenching of photoconductivity in amorphous selenium has been investigated [8]. R. M. Mehra, et. al. found that, in high

temperature region (200 to 300 *K*), the conduction mechanism was due to the localized states via thermally activated tunneling, while at lower temperatures (80 to 200 *K*) the conduction is due to variable range hopping in the localized states near the Fermi level [9]. Also, the dark conductivity below and above the glass temperature (T_g) was studied. The activation energy of *a-Se* thin films was observed to increase above the T_g and was interpreted due to the process of generation, in thermal equilibrium, of charged defects [10]. Dc dark conductivity measurements were carried out on *a-Se* thin films, prepared by thermal evaporation, in the temperature range 208 -322 K. it was found that the dc conductivity is thermally activated with activation energy $E_\sigma = 1.05 \pm 0.08\ eV$ [11]. Finally, many reports were found about the electrical and optical properties of a-Se and it compounds[12– 23].

1.4 Electrical and optical Properties of V_2O_5

Vanadium is a chemical element with the symbol *V* and atomic number 23. It is a soft, silvery gray, ductile transition metal. The formation of an oxide layer stabilizes the metal against oxidation. The element occurs naturally in about 65 different minerals and in fossil fuel deposits, it is produced from steel smelter slag and from the flue dust of heavy oil or as a byproduct of uranium mining. It has many important compounds among which are Vanadium oxide (V_2O) and Vanadium pent-oxide (V_2O_5). These oxides have many useful characteristics. The aqueous sol of molten V_2O_5 into distilled water was used to prepare thin films of vanadium dioxide V_2O [24]. Therefore, they are used in a very wide range of applications especially in designing gas sensors since they form a very good sensitive catalyst materials for many gases. Our concern in this study will be on V_2O_5 which is the most important compound of Vanadium. It is a chemical compound with an orange color in its solid powder form.

Many methods of preparation, each with a certain conditions, were used to prepare V_2O_5 thin films. A. L. Pergament et.al. found the effect of an electric field on the optical and electrical properties of $V_2O_5{:}nH_2O$ gel films[25]. The effect of Molybdenum on the electrical and optical properties of thin films of V_2O_5 prepared by thermal evaporation was studied by M. F. Al-Kuhaili et. al. [26]. They found that films prepared by this technique contains a large amount of molybdenum which affect their properties. This was due to the high boiling point of V_2O_5 which is close to the melting point of Mo. This encourage some atoms of Mo to stick and evaporate with V_2O_5 molecules. Dc reactive magnetron sputtering technique was used by Li-Jian Meng et. al. to prepare thin films of V_2O_5 on a glass substrate at different

temperatures to study its optical and structural properties [27]. The electrical and crystallization properties of V_2O_5 thin films prepared under various conditions by RF sputtering were studied by Alaa A. Akl [28]. Moreover, V. V. Putrolaynen et. al. have presented the results of selective chemical etching of amorphous V_2O_5 films after their modifications by ultraviolet (UV) radiation [29].

In the field of glass and ceramic, V_2O_5 glass compound were found to be of a very interesting properties. Nehad Tashtoush et. al. studied the compositional dependence of the electrical conductivity of calcium Vanadate semiconductors [30]. The electro-chromic properties of aqueous sol-gel derived vanadium oxide films with different thickness have been investigated [31]. R. T. Rajendra Kumar et. al. have determined various structural parameters such as lattice constants, grain size, and microstrain and dislocation density of V_2O_5 thin films prepared by vacuum evaporation. Also, the influence of deposition temperature on the structural parameters have been discussed [32]. Pulsed laser deposition technique was used by R. T. Rajendara Kumarr et. al. to prepare V_2O_5 thin films thermistor [33]. finally, many reports have been found about the physical properties of V_2O_5 and it compounds especially glass and ceramic [34 – 39].

Chapter Two

Theoretical Background

As we mentioned earlier in chapter one, there are many methods for preparing thin films. In all methods, measuring the thickness is always a crucial for both electrical and optical properties. Some instruments that used to prepare thin films are enhanced with a separate device to assist in measuring the thickness and rate of deposition like microbalance which based on an oscillator circuit (crystal). Others prepare thin films with arbitrary thickness and then different methods can be used to measure the thickness. Most of the methods depend on light interferometer devices, i. e. optical devices, which are expensive and depend on the film uniformity. Other used the trivial mechanical method. To solve the problem, far away from using any device, with a very high accuracy and depending on some easy calculated and measured quantities such as the transmittance (T) and the reflectance (R), many studies were reported about using an analytical mathematical method depending on solving two or three equations numerically to find many variables one of which is the thickness.

In this chapter we will give a brief discussion about the methods we will use to find out the film thickness of our samples. Moreover, we will show the methods and equations that used in calculating both the electrical and optical constants.

2.1 Film Thickness Measurement

The methods of determining film thickness can be summarized by the following three methods.

2.1.1 The Mechanical Method

It depends on using a very high accurate balance, to figure out how much mass was deposited on the substrate. Therefore, It is called the weight method. To determine a film thickness, few steps are required that can be summarized in the following:

1. After cleaning the substrate we find its weight by a microbalance with a very high accuracy(in our work we used METTLER AE240 model with accuracy about 0.00001 g). The measured mass is m_o.
2. The evaporation process take place, and the thin film is prepared.

3. Taking out the sample from the chamber and directly finding the weight of substrate with film by the same Microbalance. The measured mass is registered as m_1.
4. Subtracting m_0 from m_1, the result will be the mass of the material deposited on the substrate, i.e. the film mass on the substrate is $\Delta m = m_1 - m_0$.
5. Finally, the film thickness is calculated by:

$$d = \frac{\Delta m}{\rho \mathrm{A}} \qquad --- \ 2.1$$

where A is the substrate area (length times width), and ρ is the film density.

However, the film density is known to be less than that of the bulk material by about 25 to 30 %. This was attributed to the granular structure of the film[1]. To be sure of this result, we determine the thickness of several of our samples using Film Tek 3000 Film Metrology Tool, which is a device used for thickness measurement located at one of the physics labes at the Physics Department of Jordan University. We find out that the results were close. The film thickness that was used in calculation is the average value of all measurements for each film.

2.1.2 Quartz Microbalance

Another method to find film thickness is by the Quartz Microbalance, which is many kinds among which is (Edwards FTM5 Model). This method depends on knowing some physical parameters about the material under consideration, such as the density (ρ)and the acoustic impedance (Z). then, giving these to the computerized device which is connected to a quartz crystal near the sample inside the chamber, it will give us the thickness and rate of deposition.

2.1.3 The Envelope Method

This method is a mathematical method depending on knowing one measured value such as the transmittance (T) or the reflectance (R). It is good and applicable for those film which can give an interference pattern. If there are no interference pattern another analytical method should be used. If an interference pattern in the transmission curve appears with a maximum and a minimum fringes, we can find out the film thickness and other optical

parameters using what is called the envelope method. In this method, the transmittance due to a transparent film is given by [3]:

$$T = \frac{Ax}{B - Cx\cos[\frac{4\pi nd}{\lambda}] + Dx^2} \qquad \text{---2.2}$$

With

$$\mathrm{A} = 16n^2 s \qquad ---2.3\mathrm{a}$$

$$B = (n+1)^3(n+s^2) \qquad ---2.3\mathrm{b}$$

$$\mathrm{C} = 2(n^2-1)(n^2-s^2) \qquad ---2.3\mathrm{c}$$

$$\mathrm{D} = (n-1)^3(n-s^2) \qquad ---2.3\mathrm{d}$$

$$x = Exp[-\alpha d] \qquad ---2.3\mathrm{e}$$

Where *s* is the substrate refractive index.

To determine the maxima and minima of *T*, we find the first derivative *Eq. 2.2* with respect to λ , i.e.

$$\frac{\partial T}{\partial \lambda} = \frac{-Ax(-Cx^2(\frac{-4\pi nd}{\lambda^2})Sin[\frac{4\pi nd}{\lambda}])}{(B - Cx^2 Cos[\frac{4\pi nd}{\lambda}] + Dx^2)} = 0 \qquad ---2.4$$

From which we find that:

$$\sin[\frac{4\pi\, nd}{\lambda}] = 0 \qquad ---2.5$$

Which is true only if:

$$\frac{4\pi\, nd}{\lambda} = h\pi \qquad ---2.6$$

where h is an integer. Eq. 2.6 can be rewritten as:

$$2nd = \frac{h}{2}\lambda \qquad ---2.7$$

Or

$$2nd = m\lambda \qquad ---2.8$$

where $m = \frac{h}{2}$.

Now, if m is an integer and h is an even number, then the function $\cos(h\pi) = 1$, which gives a maximum value of T in Eq.2.2 . if m is half integer and h is an odd, then the function $\cos(h\pi) = -1$, which gives minimum value of T in Eq.2.2.

The refractive index of any material is a wave length dependent. Therefore, any film has many different refractive indices n_i each is associated with a wave length λ_i. For the first order fringes m_1 (with maximum or minimum T), we have $2n_1d = m_1\lambda_1$, so the order of nearest neighbor to m_1 is m_1+1. Therefore, for the nearest neighbor order we have $2n_2 d= (m_1+1) \lambda_2$.

Now $\lambda_1 (2n_2d= (m_1+1) \lambda_2)$ - $(2n_1d =m_1\lambda_1) \lambda_2$ will gives

$$2d(n_2 \lambda_1 - n_1 \lambda_2) = \lambda_2\lambda_1 .$$

so

$$d = \frac{\lambda_1\lambda_2}{2(n_2\lambda_1 - n_1\lambda_2)} \qquad ---2.9$$

Where λ_1 and λ_2 are the wave lengths in which the transmission have a maximum or minimum values with order $m_1$and m_2 respectively (λ_1 and λ_2 both must have maximum value of T or both have minimum values of T) , Eq.2.9,used to calculate the film thickness by specifying any two neighbor maximum or minimum fringes in the transmission curve, n_1 and n_2 are the refractive indices at λ_1 and λ_2, which we will show later how we were calculated it.

2.2 Determining Optical Constants Using the Envelop Method

In films at which the thickness of the substrate is several order of magnitude larger than the thickness *d*, and the film is uniform, interference pattern could be seen in the VIS and IR region of spectrum. This effect will give rise to an oscillating transmission curve. Such interference fringes will be used to determine the optical constants, as well as the thickness as mentioned in the previous section. This method is called the envelope method. It can be summarized as follows.

The transmission through any film depends on many parameters that are; wave length λ, refractive index of the substrate *s*, refractive index of the film material *n*, film thickness *d*, and the extinction coefficient *k* or the absorption coefficient α. Therefore the transmittance can be written as a function of all these parameters, i.e. $T = T(\lambda,s,n,d,k)$ which is a complex function. However, in the range of a very high transparent material, low absorption, this expression can be simplified significantly by neglecting the extinction coefficient of the film. This approximation is certainly valid over most of the spectrum of any non-absorbing material , i.e. $\alpha = 0$. In this case, the expression for the transmittance *T* then becomes as in Eq.2.2. This method was first used by Swanepol [3] and called Swanepol's method and based on the idea of Manifacier et al (1976) [40] of creating the envelope of interference maximal and minimal.

Now to calculate the refractive index in the transparent region we follow up the next steps; first, using Eq. 2.2 we determine both the maximal points and minimal points of *T*. The maximal occurs when $\cos\theta = 1$, and the minimal occurs when $\cos\theta = -1$. Applying this into Eq. 2.2 we get:

$$T_M = \frac{A\,x}{B - C\,x + D\,x^2} \qquad ---2.10$$

$$T_m = \frac{A\,x}{B + C\,x + D\,x^2} \qquad ---2.11$$

where T_M are the maximum points and T_m are the minimum points of T in the transparent region where when we use the top of fringes (maximum value of T) all T_M were taken from the real transmission curve and T_m were taken from the lower envelop at same wavelength , but when we use the bottom of fringes (minimum values of T) all T_m were taken from the real curve of T and T_M were taken from the upper envelop, and *x* is given by Eq. 2.3e.

For non-absorbing films, we have $\alpha = 0$, therefore $x = 1$ and

$$T_m = \frac{A}{B + C + D} \qquad ---2.12$$

$$T_m = \frac{4n^2 s}{n^4 + n^2(s^2 + 1) + s^2} \qquad ---2.13$$

by solving the last equation for *n* we get

$$T_m n^4 + T_m(s^2 + 1)n^2 + T_m s^2 = 4n^2 s \qquad ---2.14$$

or

$$T_m n^4 + (T_m(s^2 + 1) - 4s)n^2 + T_m s^2 = 0 \qquad ---2.15$$

Assuming that $y = n^2$ then $y^2 = n^4$, Eq. 2.15 becomes

$$T_m \; y^2 + [T_m \; (s^2 + 1) - 4s\,]y + T_m \; s^2 = 0 \qquad ---2.16$$

Solving for *y* we get

$$y = \frac{-[T_m \; (s^2 + 1) - 4s]}{2T_m} \pm \frac{\sqrt{([T_m \; (s^2 + 1) - 4s]^2) - 4T_m^{\;2} \; s^2}}{2T_m}$$

$$= \frac{2s}{T_m} - \frac{(s^2 + 1)}{2} \pm \sqrt{([\frac{-1(4s - T_m \; (s^2 + 1))}{2T_m}]^2) - s^2} \qquad ---2.17$$

Let $M = \frac{2s}{T_M} - \frac{(s^2 + 1)}{2}$, then the last equation takes the form

$$y = M \pm \sqrt{M^2 - s^2} \qquad ---2.18$$

but $n = \sqrt{y}$, then

$$n(\lambda) = \sqrt{[M + \sqrt{M^2 - s^2}} \qquad ---2.19$$

which is the equation to be used to calculate *n(λ)* in the transparent region.

Now, return back to Eq.2.10 with $x = 1$, we find that:

$$T_M = \frac{A}{B - C + D} \qquad ---2.20$$

$$= \frac{16n^2 s}{8(n^2 + n^2 s)}$$

$$= \frac{2s}{1 + s^2} \qquad ---2.21$$

Solving previous equation for s we get

$$s = \frac{2}{2T_M} + \sqrt{\frac{4 - 4T_M{}^2}{4T_M{}^2}} \qquad ---2.22$$

$$= \frac{1}{T_M} + \sqrt{\frac{1}{T_M{}^2} - 1} \qquad ---2.23$$

Eq.2.23 is used to calculate the substrate refractive index for any wave length. In the regions of weak and absorption medium where $\alpha \neq 0$, so $x\langle 1$ to determine n(λ) in these regions, subtract the reciprocal of Eq.10 from the reciprocal of Eq.11 yields

$$\frac{1}{T_m} - \frac{1}{T_M} = \frac{B + Cx + Dx^2}{Ax} - \frac{B - Cx + Dx^2}{Ax} = \frac{2Cx}{Ax} = \frac{2C}{A} = \frac{(n^2 - 1)(n^2 - s^2)}{4n^2 s} \qquad ---2.24$$

$$n^4 - (n^2)[(s^2 + 1) + 4s(\frac{T_M - T_m}{T_M T_m})] + s^2 = 0 \qquad ---2.25$$

Now let $y = n^2$, so

$$y^2 - [(s^2+1) + 4s(\frac{T_M - T_m}{T_M T_m})]y + s^2 = 0 \qquad ---2.26$$

$$y = 2s(\frac{T_M - T_m}{T_M T_m}) + \frac{s^2+1}{2} + \sqrt{[2s(\frac{T_M - T_m}{T_M T_m}) + \frac{s^2+1}{2}]^2 - s^2} \qquad ---2.27$$

And let , $N = 2s(\frac{T_M - T_m}{T_M T_m}) + \frac{s^2+1}{2}$, so $y = N + \sqrt{N^2 + s^2}$

Thus,

$$n(\lambda) = \sqrt{y} = \sqrt{N + \sqrt{N^2 - s^2}} \qquad ---2.28$$

Eq.2.28 is used for calculating the refractive index in the weak and medium absorption region .
To calculate absorption coefficient α. where $x = Exp[-\alpha d]$, and by using Eq.2.10, to calculate x where

$$T_M = \frac{Ax}{B - Cx + Dx^2}$$

By solving previous equation for x we get

$$Ax = BT_M - CxT_M + Dx^2 T_M \qquad ---2.29$$

$$x = \frac{CT_M + A}{2T_M \ D} \pm \frac{\sqrt{(CT_M + A)^2 - 4T_M{}^2 DB}}{2T_M D}$$

$$= \frac{C}{2D} + \frac{A}{2T_M D} + \sqrt{(\frac{T_M C + A)^2}{2T_M D} - \frac{B}{D}} \qquad ---2.30$$

Substituting A,B,C and D values and let

$$E_m = \frac{8n^2 s}{T_M} + (n^2 - 1)(n^2 - s^2) \qquad ---2.31$$

then,

$$x = \frac{E_m}{(n-1)^3\ (n-s^2)} + \sqrt{\frac{E_m}{[(n-1)^3\ (n-s^2)]^2} - \frac{(n+1)^3\ (n+s^2)}{(n-1)^3\ (n-s^2)}}$$

$$x = \frac{E_m - \sqrt{E_m{}^2 - (n^2-1)^3\ (n^2-s^4)}}{(n-1)^3\ (n-s^2)} \qquad ---2.32$$

Eq. 2.32 is used to calculate x where $x = Exp[-\alpha d]$ and

$$\alpha = \frac{-\ln x}{d} \qquad ---2.33$$

Eq.2.33 is used to calculate absorption coefficient .
T_M and T_m are the transmission maximum and the corresponding minimum at a certain wavelength λ, one being measured and the other calculated . The intermediate values have been derived by a suitable computer program, where these points have been used in order to construct two smooth envelopes [3,1].

2.3 Determination of Optical Constants Using T and R measurements

For a single absorbing layer on a transparent substrate, such as vanadium pentoxide thin films on a glass substrate, it is easy to measure the reflectance from the film side *(R)*, the reflectance from the substrate side *(R`)*, and the transmittance through the film *(T)*. Using these measurements we can find the optical constants of the film material by solving the theoretical equations that gives the values of transmittance and reflectance. These relation for T and R can be easily approved, and found to be as [1]:

$$T = \frac{s}{n_0}\ \frac{[(1+g_1)^2 + h_1{}^2][(1+g_2)^2 + h_2{}^2]}{Exp[2\beta] + ((g_1{}^2 + h_1{}^2)(g_2{}^2 + h_2{}^2)Exp[-2\beta]) + C\ Cos[2\gamma] + DSin[2\gamma]} \qquad ---2.34$$

$$R = \frac{(g_1{}^2 + h_1{}^2)\ Exp[2\beta] + (g_2{}^2 + h_2{}^2)Exp[2\beta] + A\ Cos[2\gamma] + B\ Sin[2\gamma]}{Exp[2\beta] + (g_1{}^2 + h_1{}^2)(g_2{}^2 + h_2{}^2)\ Exp[2\beta] + C\ Cos[2\gamma] + D\ Sin[2\gamma]} \qquad ---2.35$$

$$R' = \frac{(g_2{}^2 + h_2{}^2)Exp[2\beta] + (g_1{}^2 + h_1{}^2)Exp[-2\beta] + ACos[2\gamma] + BSin[2\gamma]}{Exp[2\beta] + (g_1{}^2 + h_1{}^2)(g_2{}^2 + h_2{}^2)Exp[-2\beta] + CCos[2\gamma] + DSin[2\gamma]} \qquad ---2.36$$

where

$$h_1 = \frac{2n_0k}{(n_0+n)^2+k^2}$$

$$h_2 = \frac{-2sk}{(n+s)^2+k^2}$$

$$g_1 = \frac{n_0^{\ 2}-n^2-k^2}{(n_0+n)^2+k^2}$$

$$g_2 = \frac{n^2-s^2\ \ +k^2}{(n+s)^2+k^2}$$

$$\beta = \frac{2\pi kd}{\lambda}$$

$$\gamma = \frac{2\pi nd}{\lambda}$$

where d is the film thickness, k is the extinction coefficient of the film, s is the refractive index of the substrate, n is the refractive index of the film material, and n_o is the refractive index of air. Solving Eq.2.34 ,Eq.2.35 and Eq.36, by a suitable computer program we can find n and k, then we can use k to find the absorption coefficient α which is related to k by :

$$\alpha = \frac{4\pi k}{\lambda} \qquad ---2.37$$

Electrical calculations

In this section we will show the methods which used to calculate the resistance R and the conductivity of the films σ where we used the Two – Point probe method with

$$R = \frac{V}{I} \qquad ---2.38$$

$$\sigma = \frac{1}{\rho} \qquad ---2.39$$

$$\rho = \frac{\mathrm{WdR}}{\mathrm{L}} \qquad ---2.40$$

Where V is the source voltage, I is the current that passes through the film between the two electrodes, W is the spacing between the two electrodes , d is the film thickness, L is the electrodes length and ρ is the film resistivity .
But the most popular method to calculate the conductivity which show the dependence of conductivity on the temperature, which represented as

$$\sigma = \sigma_0 \; Exp\left[\frac{-E_a}{KT}\right] \qquad ---2.41$$

Where σ_0 is a constant, E_a is the activation energy that required for a charge carrier to hop from one side to another, K is the Boltzmann's constant and T the absolute temperature .
These equations were used to find the electrical calculation for the Se and V_2O_5 films[41] .

Chapter Three

Experimental Procedure

In this work we have prepared ten samples of V_2O_5 thin films and six samples of Se thin films. All samples were prepared using the thermal evaporation technique. This was achieved by using Edwards coating system E306 A model. All samples (thin films) were deposited on a glass substrates with a refractive index of about 1.52. The substrates were cleaned by the usual method of cleaning that is: using the ultrasound cleaner filled with acetone to clean the substrates, then filled with distilled water. After this, all substrates were cleaned again with methanol and then with distilled water. Finally, a hot clean air was used to dry the substrates.

To prepare a certain sample with a certain thickness, the substrate was attached to a special holder in the evaporator, then a powder of V_2O_5 of purity 98.5%, or Se of purity 98.8% were added to the Mo boat, which was 12 cm away from the substrate, before closing the chamber to start the evacuation and evaporation process. The base pressure inside the chamber was less than 10^{-5} mbar. The thicknesses of films (Se thin films) were controlled and monitored using a quartz crystal thickness monitor of the type Edwards FTM5 model .

In each deposition process two samples were prepared for different purposes of films characterization. After the films were deposited, they were removed from the coating chamber, and a variety of characterization techniques were employed to study their various properties.

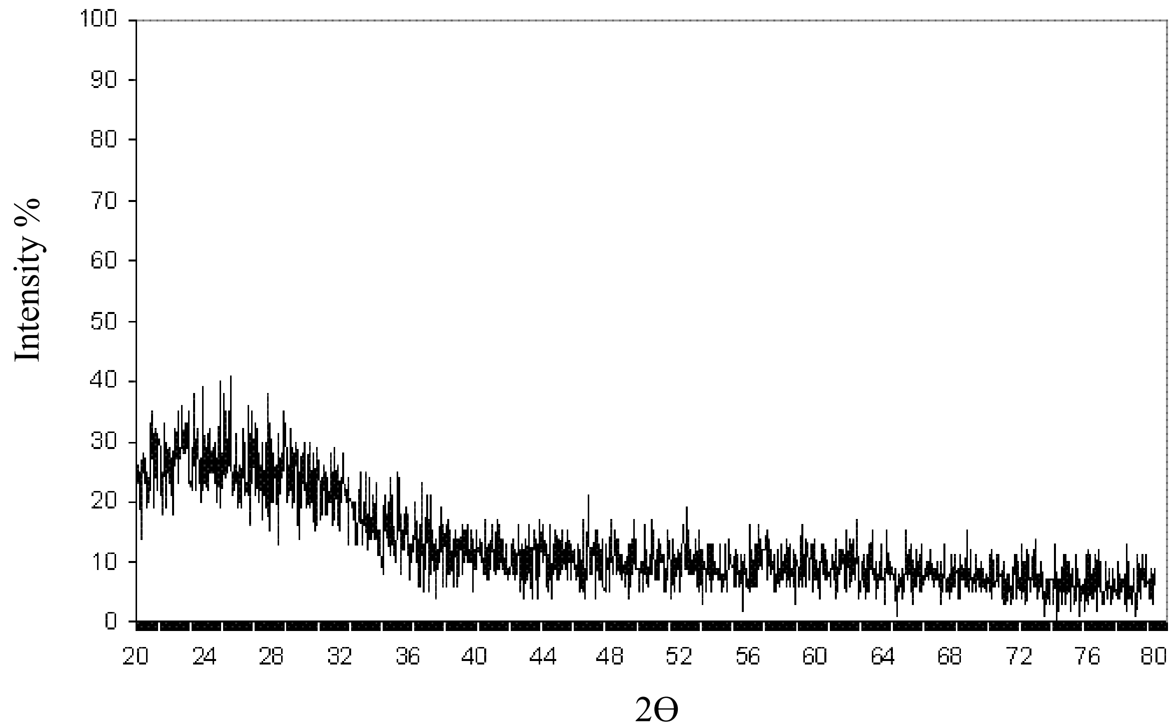
The normal incidence reflectance (*R*) and transmittance (*T*) of the films were measured over the range of 300 nm to 900 nm wavelength. A spectrophotometer, Specord M500 model, was used.

The dc conductivity of the films were measured both at low and at high temperatures. For low temperature, a special cryostat that is connected to a vacuum system and liquid nitrogen inlet was used. The base pressure inside the cryostat was about 5 x 10^{-5} mbar. The temperature was changed from room temperature down to – 100 ^oC. For high temperature study, a home made furnace was used. The sample was heated from room temperature up to 250 ^oC. The dc conductivity was measured using Keithly 617 Programmable Electrometer. For the electrical measurement, two thin Aluminum films were deposited over the surface of V_2O_5 and Se films to work as an electrodes. The spacing between the electrodes is 2 mm and its length is 20 mm). A Platinum wires were connected to the electrodes using silver paste.

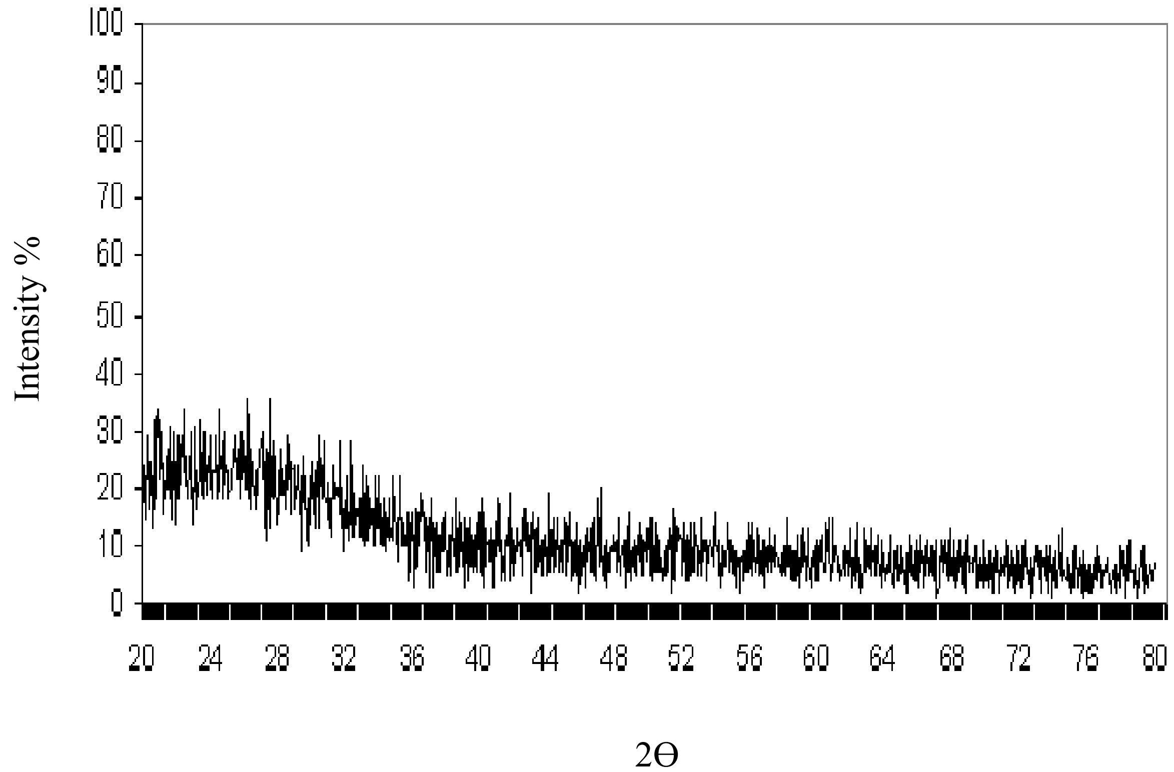
Chapter Four

Results and Discussions

Many experiments have been conducted to study the optical and electrical properties of both *a-Se* and V_2O_5 thin films. Therefore, we will split our discussion into four sections; the first two sections will be related to the optical properties of our samples, and the other two sections will be related to the electrical properties of the same samples. Before measurements, XRD pattern assured that our sample are amorphous. Fig. (4.1) shows the XRD pattern for the as deposited Se thin film and Fig. (4.2) shows the XRD pattern for the as deposited V_2O_5 thin film.



Figure(4.1): The X-ray diffraction pattern of as deposited Se thin film on glass substrate.



Figure(4.2): The X-ray diffraction pattern of as deposited V_2O_5 thin film on glass substrate.

4.1 Optical properties of *a-Se* thin films

In order to measure the optical properties of a-Se thin films, using the envelope method, an experiment was conducted using the spectrophotometer to measure transmittance (T) of that film.

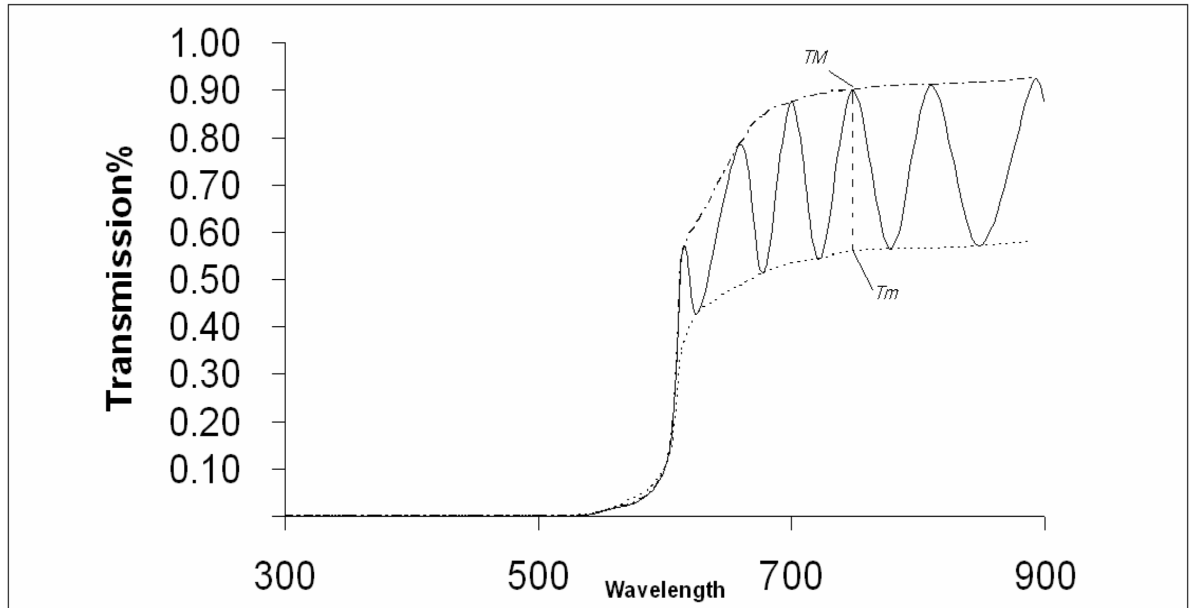


Figure (4.3):

The transmission spectrum (full curve) for a 1580 nm a-Se thin film on a glass substrate.

Fig. (4.3) shows a typical transmittance curve (spectrum) of Se thin film with thickness of 1580 nm. The curve shows an interference fringes on the high transmittance (low absorption) region of wavelength. The curve can be split into three regions, the first region is the strong and medium absorption region which appears in the interval (300 nm –700 nm), the second region appears in the interval (700 nm -810 nm) and known as the weak absorption region, and the third region is the transparent region appears from 810 nm to 900 nm.

It is important to mention that the photons with energies less than band gap are transmitted, on the other hand the photons with energies greater than or equal to band gap can be absorbed, where a photon with energy less than E_g is unable to excite an electron from the valance band to the conduction band, thus in a pure semiconductor there is a negligible absorption of photons with $h\upsilon < E_g$. This explains why some materials are transparent, like our sample, in certain wavelength range [42].

In order to determine the optical properties we have to build up two curves, that are T_M curve which is related to the maximum points at which the interference took place and T_m curve which is related to the points at which minimum points at which the interference took place values of T_M and T_m are shown in table (4.1) where the bolded data were taken from the experimental

curve and the underlined data were taken from the envelope curves . T_M and T_m are considered to be continuous function of λ. Also, the refractive index is a function of λ, *n(λ)*. The two curves of T_M and T_m formed the envelope of the T curve as shown in Fig. (4.3). These curves are constructed using three point extrapolation. As it indicated in Fig. (4.3) we see that at any λ, for any value of T_M there is a corresponding value of T_m. We measure the refractive index of the substrate using T_M value in the transparent region using Eq. 2.23. It was found to be 1.52.

Fig. (4.4) represent the refractive index for as deposited Se thin film. The refractive index values were calculated using equations (2.18) and (2.19). It was found that the refractive index decreases from 2.815 to 2.615 as λ increases from 632 to 890 nm, which represented by the dot points in the figure. Now the values of *n(λ)* can be fitted to a reasonable function such as the two-terms Cauchy dispersion

Table 4.1

T_M and T_m values for 1580 nm Se thin film .

no	λ (nm)	T_M	T_m
1	632	**0.56**	*0.385*
2	642	*0.66*	**0.432**
3	660	**0.784**	*0.485*
4	678	*0.846*	**0.513**
5	700	**0.874**	*0.533*
6	722	*0.892*	**0.544**
7	748	**0.9**	*0.558*
8	778	*0.907*	**0.563**
9	810	**0.91**	*0.565*
10	848	*0.915*	**0.57**
11	890	**0.92**	*0.58*

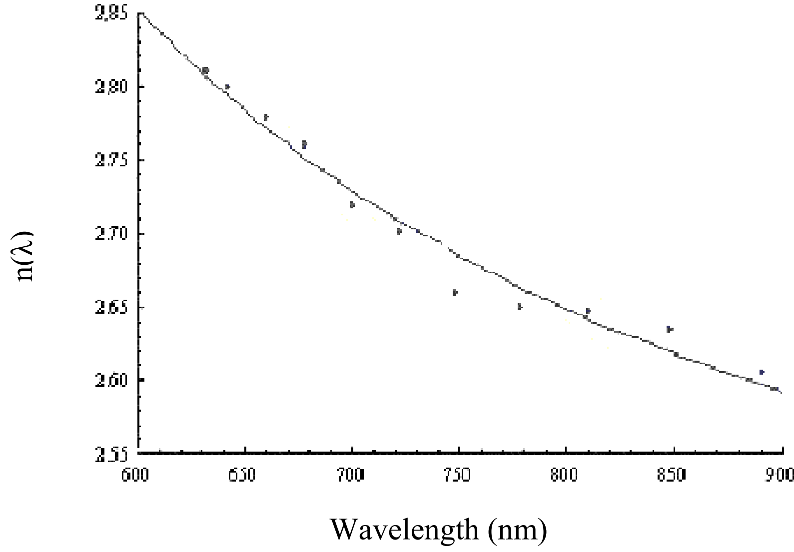


Figure (4.4): Refractive index of Se (1580nm) film versus wavelength.

relationship, $n(\lambda) = a + \frac{b}{\lambda^2}$, which can be used for extrapolation to shorter and longer wavelengths. The fit of the values of *n(λ)* yields $n(\lambda) = 2.385 + \frac{168385}{\lambda^2}$. The full curve in Fig. (4.4) represents this function.

Fig. (4.5) shows the absorption coefficient *α(λ)* for this film, which was calculated by using equation (2.33) with the help of equations of (2.31) and (2.32). From the plot, it appears that the absorption coefficient decreases from 0.00024712 to 0.00000379 per (cm*10^{-7}) as wavelength increases from 632 to 890 nm. Moreover, the absorption coefficient is high at the low region of wavelength while it becomes zero (no absorption) at high wave lengths as indicated and shown on the T curve, i.e. Fig. (4.3).

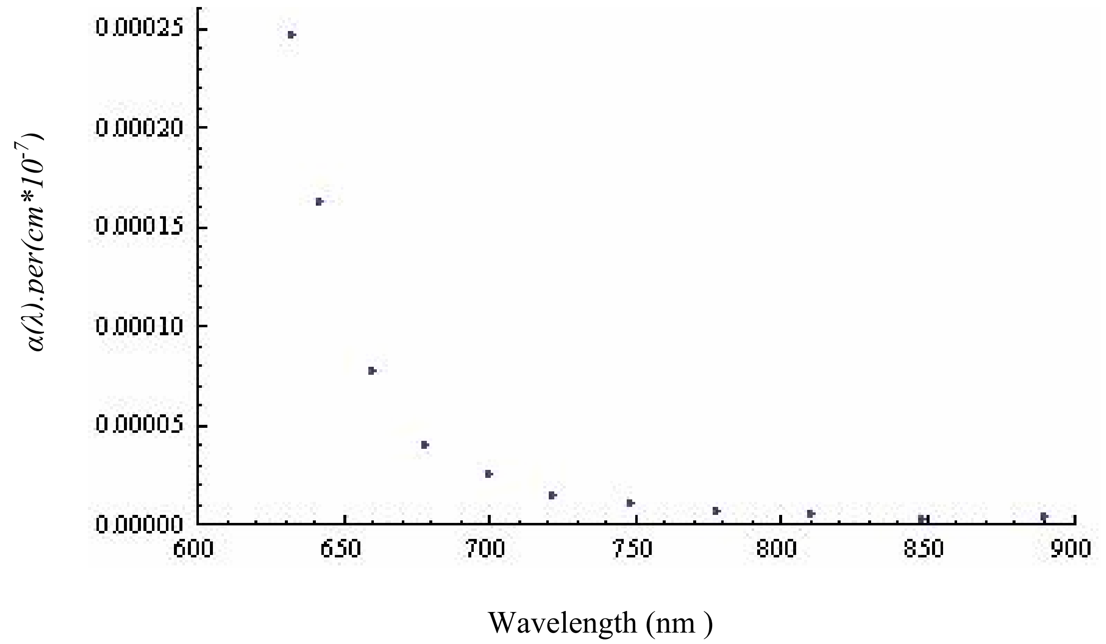


Figure (4.5): Absorption coefficient of as deposited Se (1580nm) thin film versus wavelength.

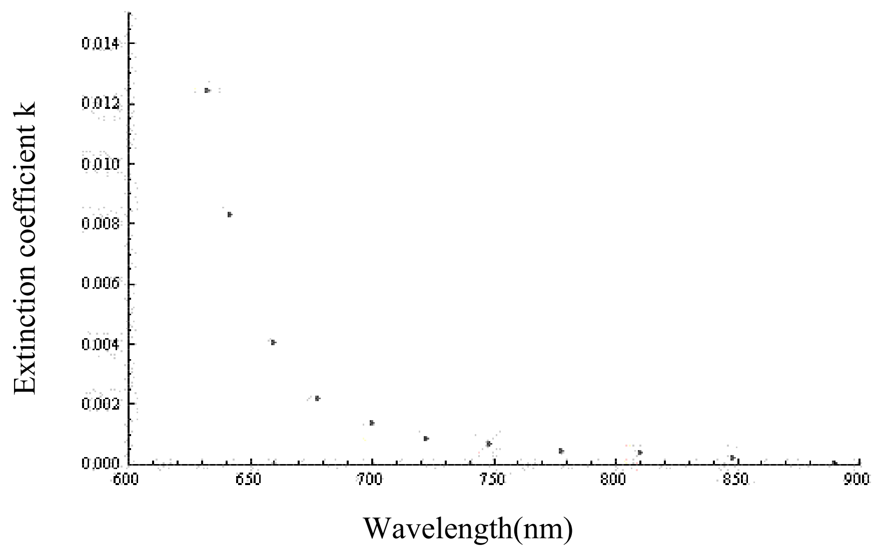


Figure (4.6): Extinction coefficient of as deposited Se (1580nm) thin film against wavelength.

The variation of extinction coefficient versus wavelength is shown in Fig. (4.6). The extinction coefficients were calculated by using equation (1.2). It appears that the extinction coefficient decreases from 0.01243 to 0.000026816 as wavelength increases from 632 to 890 nm.

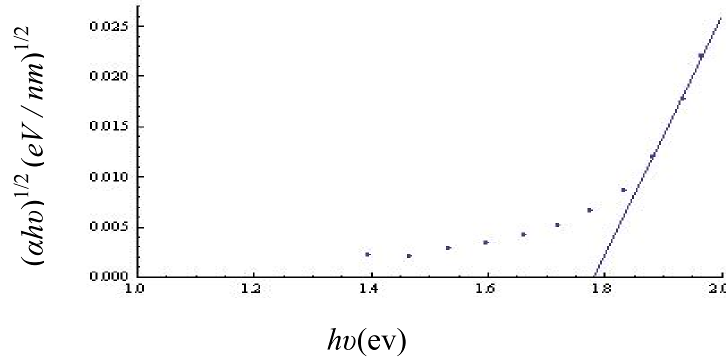


Figure (4.7) :$(\alpha hv)^{1/2}$ versus (hv) plot for 1580 nm Se thin film .

In order to measure the energy gap of the Se film, we plot the relation between $(\alpha hv)^{1/2}$ and *(hv)*. With help of $h\alpha v = A(hv - E_g)^2$, where is A constant. Fig. (4.7) shows this relation. The energy gap of a-Se thin film was found to be approximately 1.783 eV which is consistent with other previous studies [26].

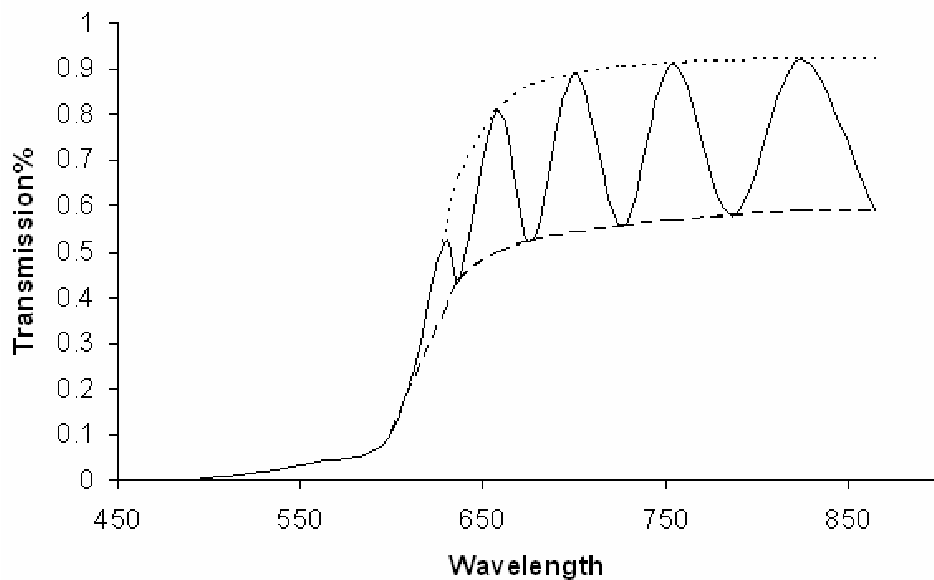


Figure (4.8): The transmission spectrum (full curve) for a 1400 nm a-Se thin film on a glass substrate**.**

Fig. (4.8) shows the transmission spectrum in the range 450 to 900 nm wavelength for a 1400 nm a-Se thin film. The spectrum can be classified to three regions, first region is the strong and medium absorption region which appears in the interval 450 nm to 650 nm, the second region appears in the interval 650 nm to 800 nm which called the weak absorption region, and the third region is the transparent region which appears from 800 nm to 900 nm. The measurement can be carried out as in the previous spectrum in Fig. (4.3). Table 4.2 shows TM and Tm values for this film , the bolded data taken from the experimental curve and underlined data taken from the envelop curves.

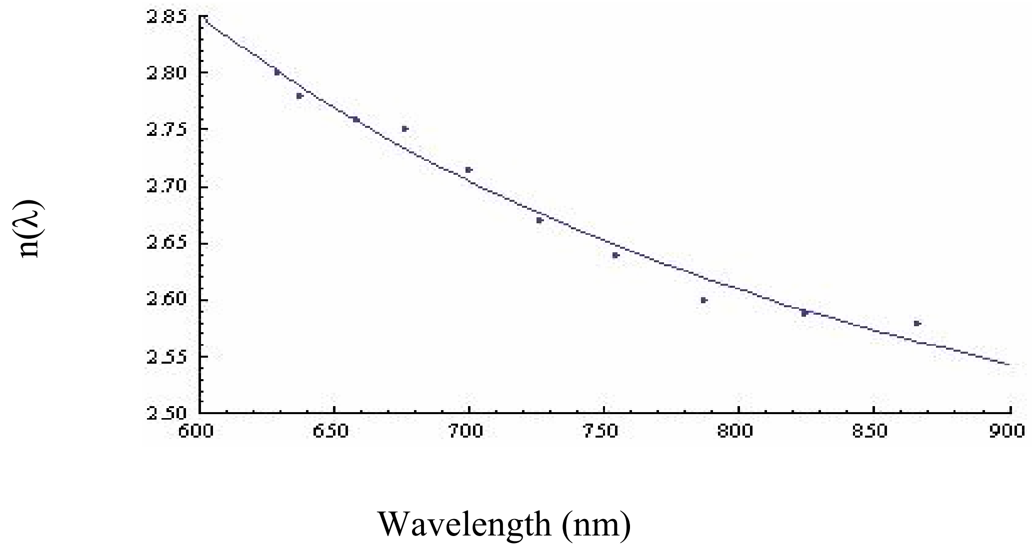
Table 4.2 .

T_M and T_m values of 1400 nm Se thin film.

no	λ (nm)	T_M	T_m
1	628	**0.516**	*0.365*
2	637	*0.662*	**0.435**
3	658	**0.808**	*0.498*
4	676	*0.862*	**0.521**
5	700	**0.89**	*0.54*
6	726	*0.903*	**0.556**
7	754	**0.91**	*0.567*
8	787	*0.9151*	**0.58**
9	824	**0.92**	*0.585*
10	866	*0.92*	**0.587**

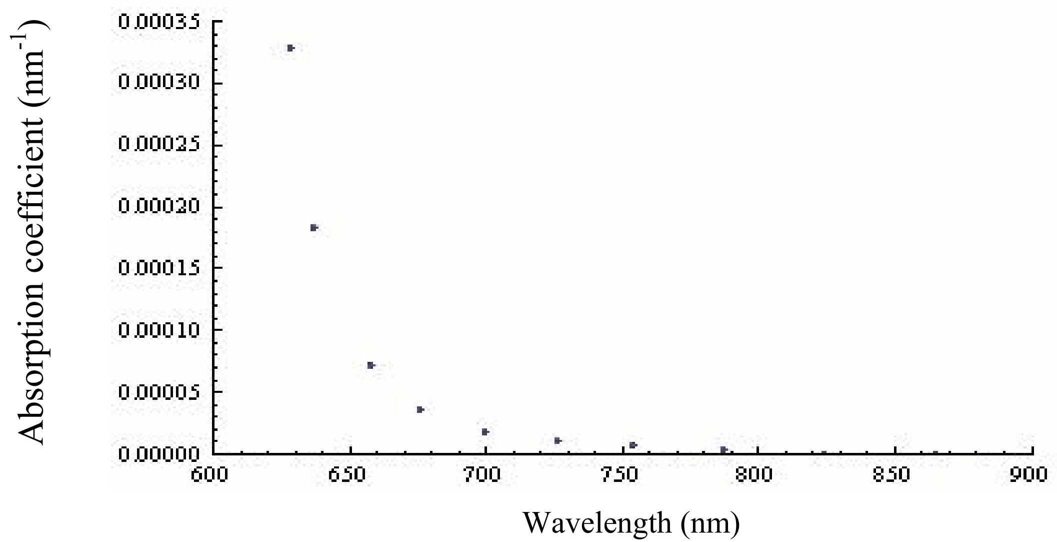
The variation of refractive index of 1400 nm a-Se thin film shown in Fig. (4.9) as a dot curve. It appears that the refractive index decreases from 2.8 to 2.58 as wavelength increases from 628.57 nm to 865.71 nm. The refractive index was measured by using envelope method [6,8], where T_M and T_m were measured from the two envelopes shown by dotted curves in Fig. (4.8). The full curve in Fig. (4.9) represents the fitted curve for refractive indices versus wavelengths data. The data were fitted to the two–terms Cauchy dispersion relationship and was found to be $n(\lambda) = 2.29812 + \frac{199032}{\lambda^2}$. This function can be used to find the refractive index at any wavelength for this film .

The absorption coefficient *α(λ)* versus wavelength for 1400 nm as deposited Se thin film is shown in Fig. (4.10). As the Figure shows, *α(λ)* decreases from 0.000328 to 0.00000043 nm^{-1} as wavelength increases



Figure(4.9): Refractive index of Se (1580nm) film against wavelength .

from 628 nm to 865 nm. The dot curve in Fig. (4.10) show the behavior of absorption coefficient as wavelength increases .



Figure(4.10): Absorption coefficient of as deposited Se (1400 nm) thin film against wavelength.

For as deposited Se thin film with thickness 1400 nm the extinction coefficient *k(λ)* as a function of wavelength was plotted in Fig. (4.11). It shows that the extinction coefficient decreases from 0.01641 to 0.00003 as wavelength increases from 628 nm to 865 nm .

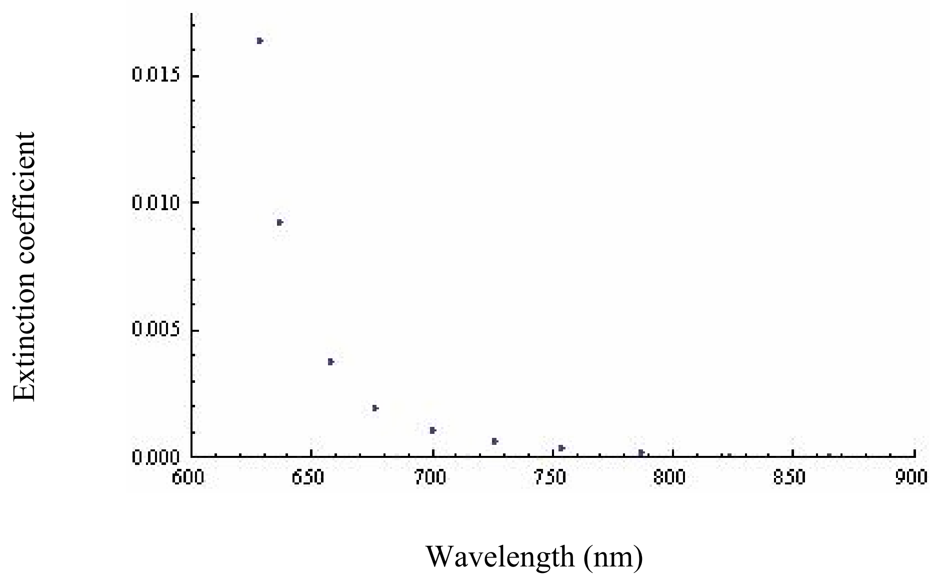


Figure (4.11) : Extinction coefficient of as deposited Se (1400 nm) thin film against wavelength

In Fig.(4.12), $(\alpha h\upsilon)^{1/2}$ versus $h\upsilon$ was plotted to determined the energy gap of the film. It was found to be about 1.815.

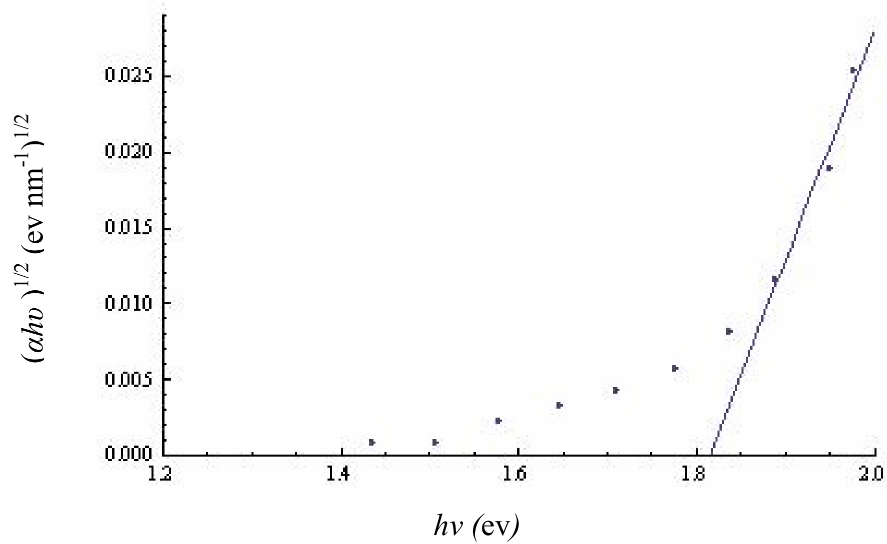


Figure (4.12):$(\alpha h\upsilon)^{1/2}$ versus ($h\upsilon$) plot for 1400 nm a-Se thin film

4.2 Optical properties of vanadium pentoxide thin film

An experiment was conducted on a thin film of V_2O_5 with thickness of 320 nm to measure its optical constants. Fig. (4.13) shows the transmittance (T) curve as a function of wavelength for this film. The transmittance

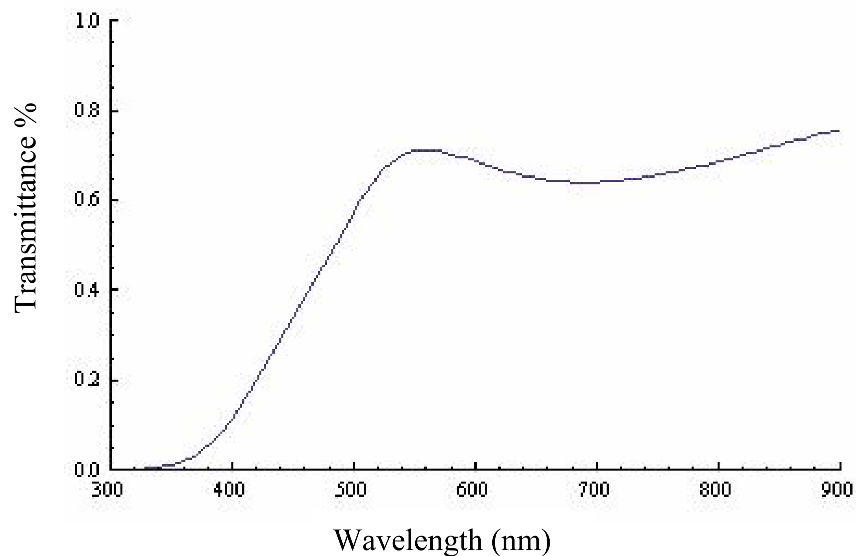
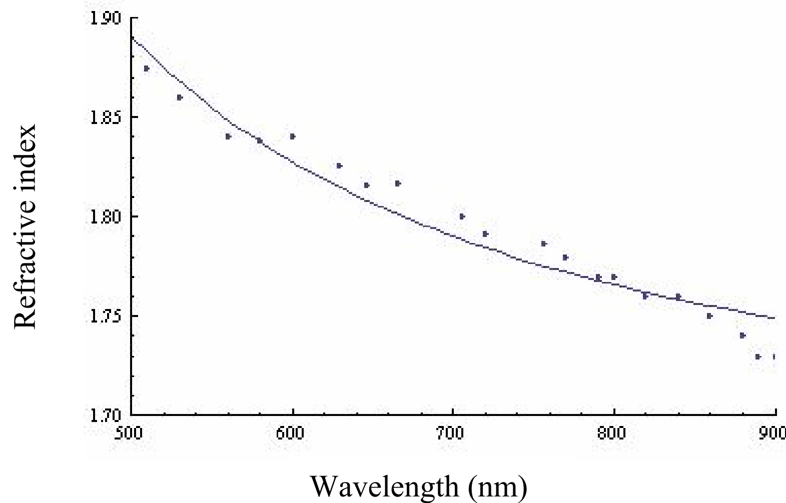


Figure (4.13): The transmission spectrum for a 320 nm V_2O_5 thin film deposited on a glass substrate

was measured from 300 nm to 900 nm. In this film it is clearly appear that there is no interference fringes. Therefore, we can not use the envelope method to find the optical constants. Also, the transparent region for this film do not appear in this interval of wavelength, since we expect to have it at the very high RF range.

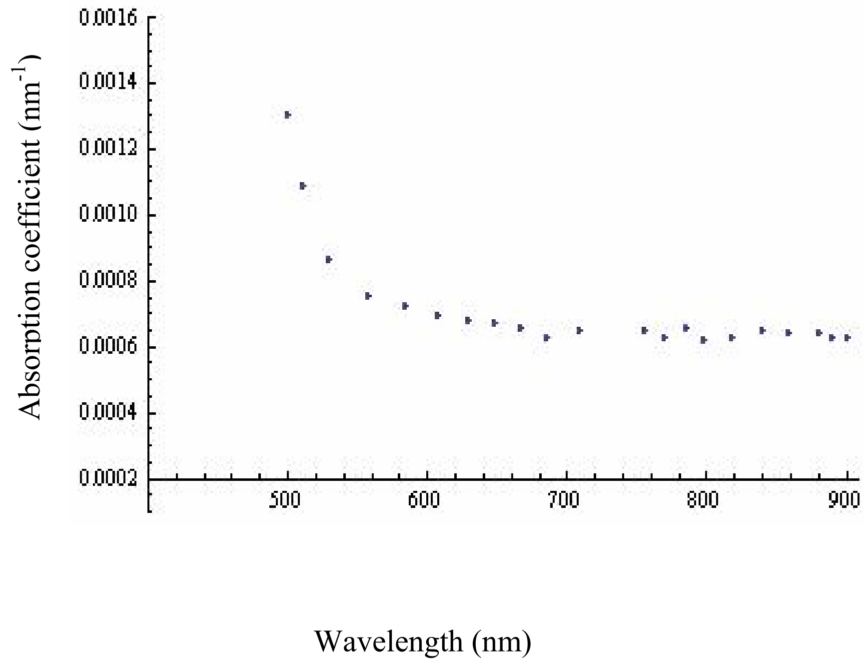
In order to find the optical constants for this kind of thin films, we have to measure the transmittance (T) and the reflectance (R) using the spectrophotometer with a special kit for R measurement. Then we use a mathematical method for solving a non linear system of equations, Equation (2.34) and Equation (2.35), using a computer program based on Mathematica. The output of the program will be the refractive index $n(\lambda)$ and the extinction coefficient $k(\lambda)$.

Fig. (4.14) shows the refractive index versus wavelength for a film of V_2O_5 of thickness of 320 nm. The measured data of $n(\lambda)$ are shown as a dot curve on Fig. (4.14). It appears that the refractive index decreases from 1.88 to 1.73 as wavelength increases from 500 nm to 900 nm. The full curve in Fig. (4.14) represents the fitted data curve where the data have been fitted to the two-term Cauchy formula and we get the function $n(\lambda) = 1.68606 + \frac{51020.2}{\lambda^2}$. This Cauchy formula can be used to calculate the refractive index at any wavelength.



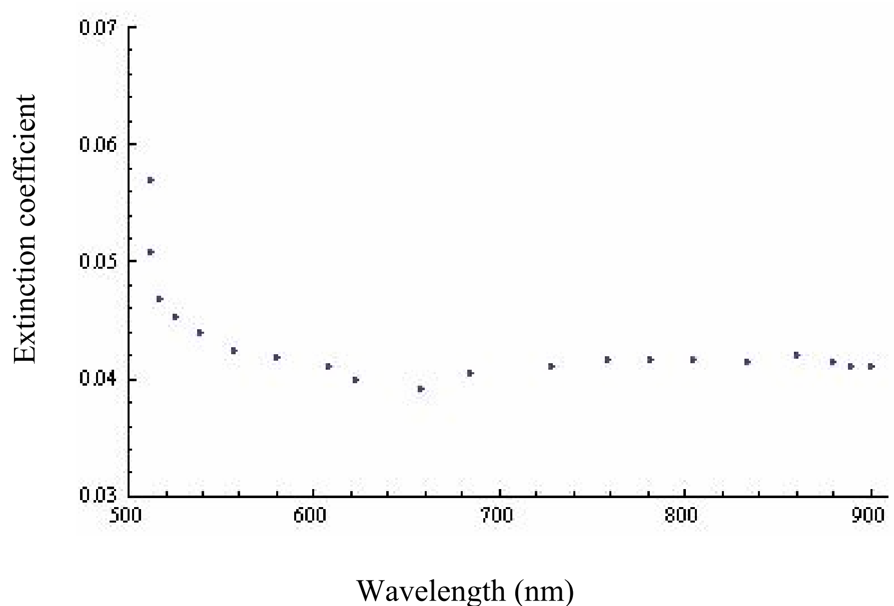
Figure(4.14): Refractive index of V_2O_5 (320 nm) film against wavelength

The absorption coefficient against the wavelength for V_2O_5 thin film with thickness of 320 nm is described by Fig. (4.15).



Figure(4.15): Absorption coefficient of as deposited V_2O_5 (320 nm) thin film against wavelength.

From the figure we see that the absorption coefficient decreases from 0.0013 nm^{-1} to 0.0007 nm^{-1} in the range of 500 nm to 620 nm. After this value of wavelength it becomes almost constant and equals to about 0.0007 nm^{-1}, from 620 to 900 nm.



Figure(4.16): Extinction coefficient of as deposited V_2O_5 (320 nm) thin film against wavelength.

Fig.(4.16) shows the extinction coefficient variation versus wavelength variation. The extinction coefficient for this film decreases from 0.057 to about 0.039 as wavelength increase from 500 nm to 640 nm. Then up to 900 nm the extinction coefficient will be constant and have the value of about 0.039 .

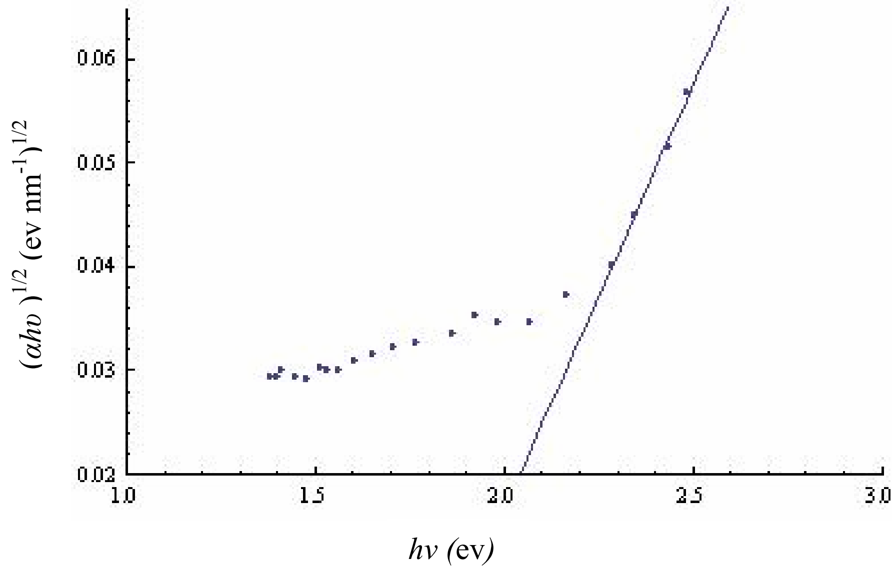
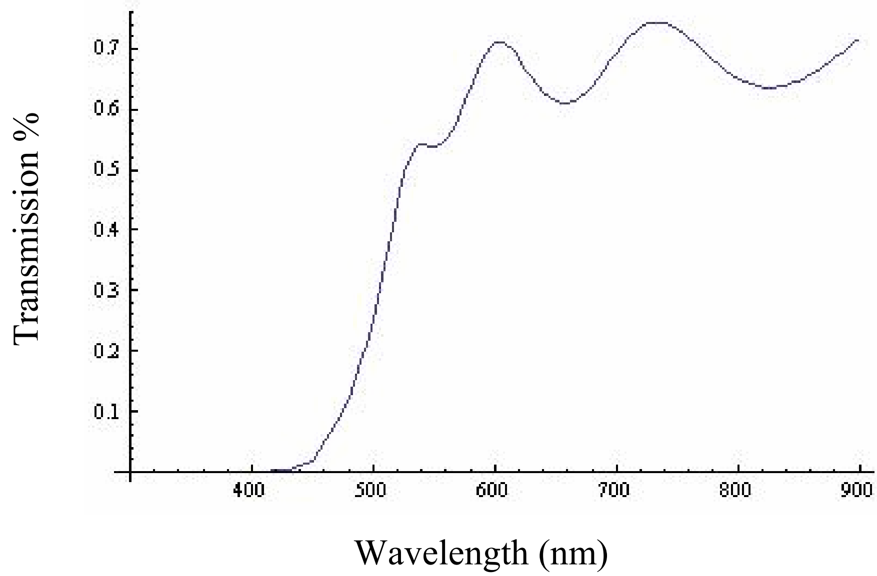


Figure (4.17): $(\alpha hv)^{1/2}$ versus (hv) plot for 320 nm a-V_2O_5 thin film

In order to measure the energy gap of this thin film, Fig. (4.17) shows the relation between $(\alpha hv)^{1/2}$ and *(hv)*, from which we calculate the energy gap, E_g , and found to be about 2.05 eV which is consistent with other studies[11].

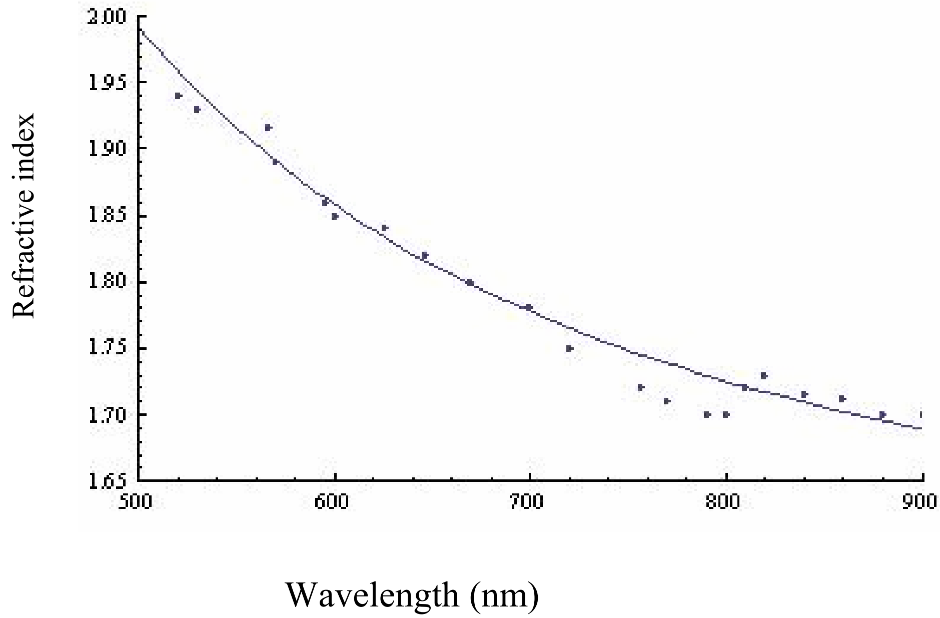
Another V_2O_5 thin film with a thickness of 700 nm was prepared and all its optical constants were calculated using the same method.

Fig. (4.18) shows the transmittance of the film as a function of wavelength in the range from 300 nm to 900 nm. It appears that the film has no transmittance in the range of 300 nm to 420 nm. The film in this interval of wavelength has a strong absorption, in the region from 420 nm to 540 nm the film has weak absorption and a medium absorption region from 540 nm to 900 nm. The transparent region will appear in region larger than 900 nm. The interference fringes appears for this film but we will not use the method of envelope to calculate the optical constants because the fringes is not sufficient, the method of envelop need more than four maximum value and the same number of minimum value, and here we have not a transparent region, where the last maximum value of transmission is about 0.74 only.



Figure(4.18): The transmission spectrum for a 700 nm a-V_2O_5 thin film on a glass substrate**.**

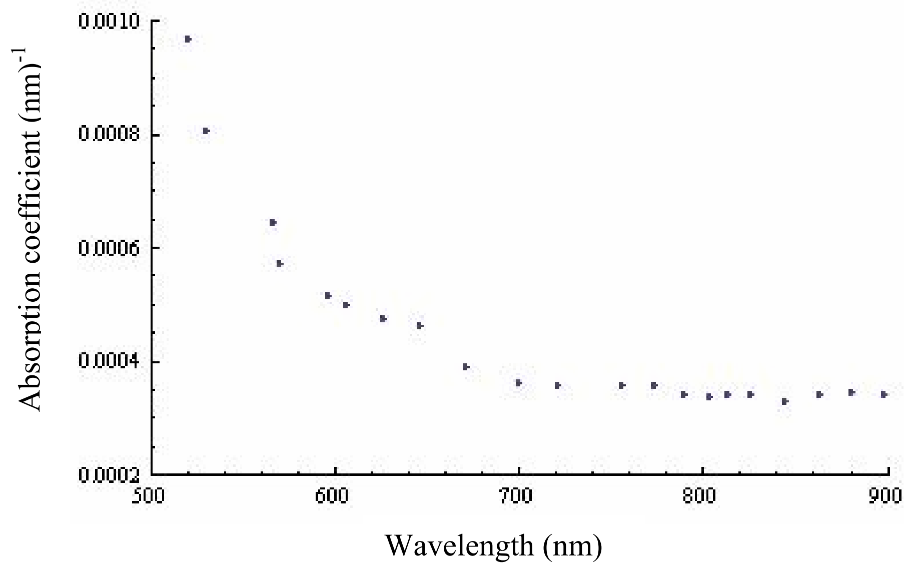
Fig. (4.19) shows the refractive index variation versus wavelength of 700 nm of V_2O_5 as deposited thin film in interval from 500 nm to 900 nm. The measured data is shown as a dot curve and it decreases from 1.94 to1.7 as wavelength increases from 520 nm to 900 nm.



Figure(4.19): Refractive index of V_2O_5 (700 nm) film against wavelength .

The full curve represents the fitted data curve where the data were fitted to the two-term Cauchy formula, and the result constants and function is given by $n(\lambda)=1.55465+\frac{109243}{\lambda^2}$. The previous Cauchy formula can be used to calculate the refractive index at any wavelength.

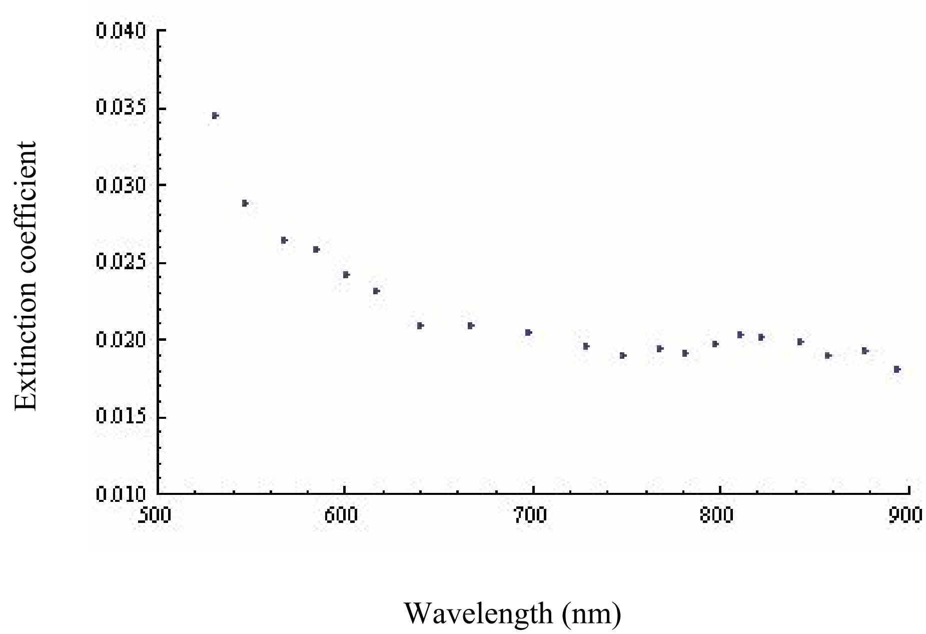
Now Fig. (4.20) shows the absorption coefficient values versus wavelength for 700 nm V_2O_5 thin film where it is clear that the absorption



Figure(4.20): Absorption coefficient of as deposited V_2O_5 (700 nm) thin film against wavelength.

coefficient decreases from 0.0009666 to 0.00035nm^{-1} as wavelength increases from 520 nm to 700 nm then it will be constant and equal to 0.00035 nm^{-1} in the interval of wavelength from 700 nm to 900 nm.

Fig. (4.21) shows the behavior of the extinction coefficient against the wavelength. It appears that the extinction coefficient decreases from 0.035 to 0.018 as wavelength increase from 500 nm to 900 nm.



Figure(4.21): Extinction coefficient of as deposited V_2O_5 (700 nm) thin film against wavelength.

Finally to calculate the gap energy we have plotted $(\alpha h\upsilon)^{1/2}$ versus $(h\upsilon)$. This relation is shown in Fig. (4.22) from which we calculate the energy gap and found to be about 1.87eV and is consistent with other studies [11].

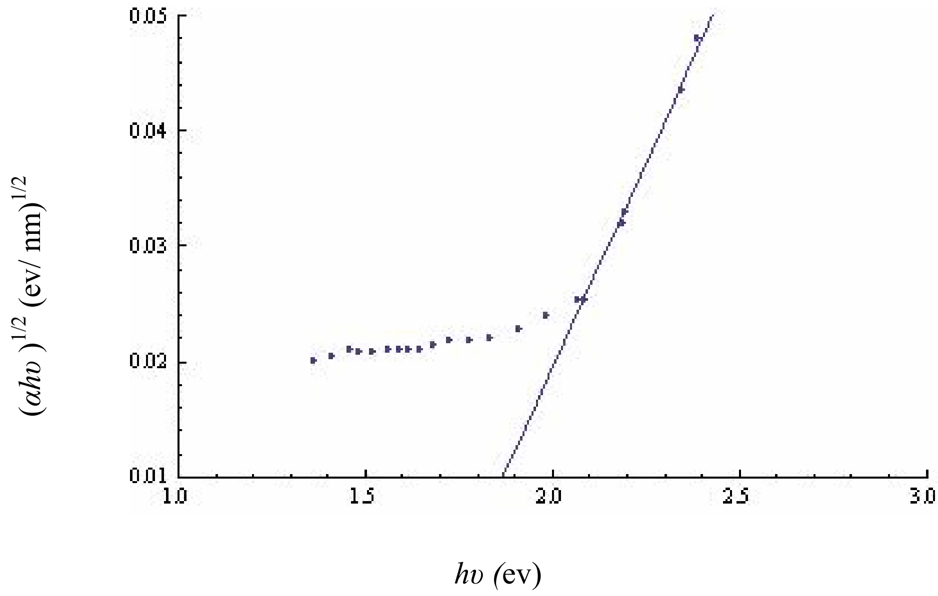


Figure (4.22): $(\alpha h\upsilon)^{1/2}$ versus ($h\upsilon$) plot for 700 nm a-V_2O_5 thin film.

4.3 Electrical properties of selenium thin film

In order to measure the electrical conductivity and its behavior against changing temperature, many experiments have been conducted. Fig. (4.23) shows the relation between Log(σ) against 1000/ T (K^{-1}), where sigma represents the film conductivity and T is the absolute temperature which changes from 290 K up to 370 K. As indicated in Fig. (4.23),

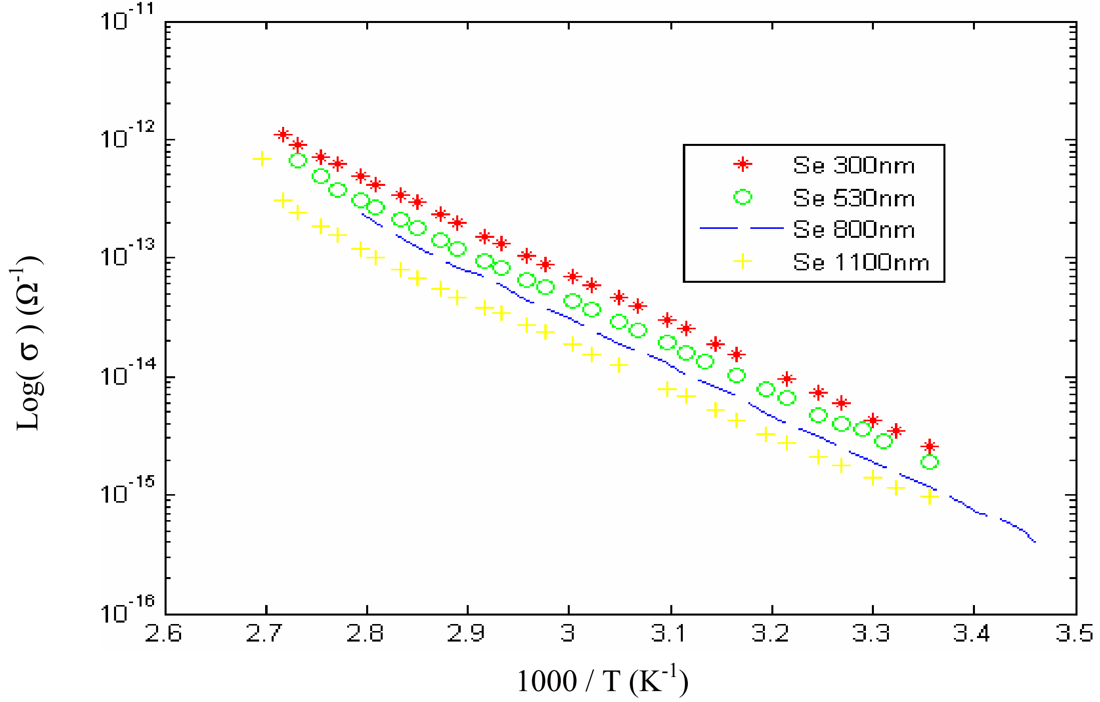
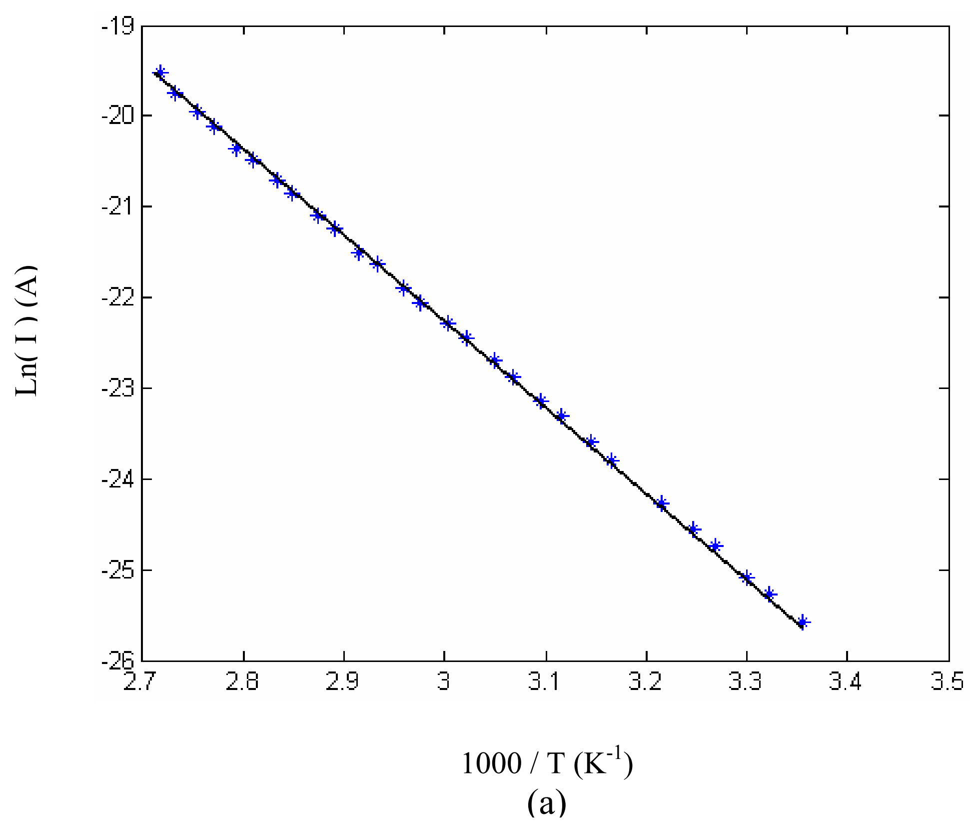
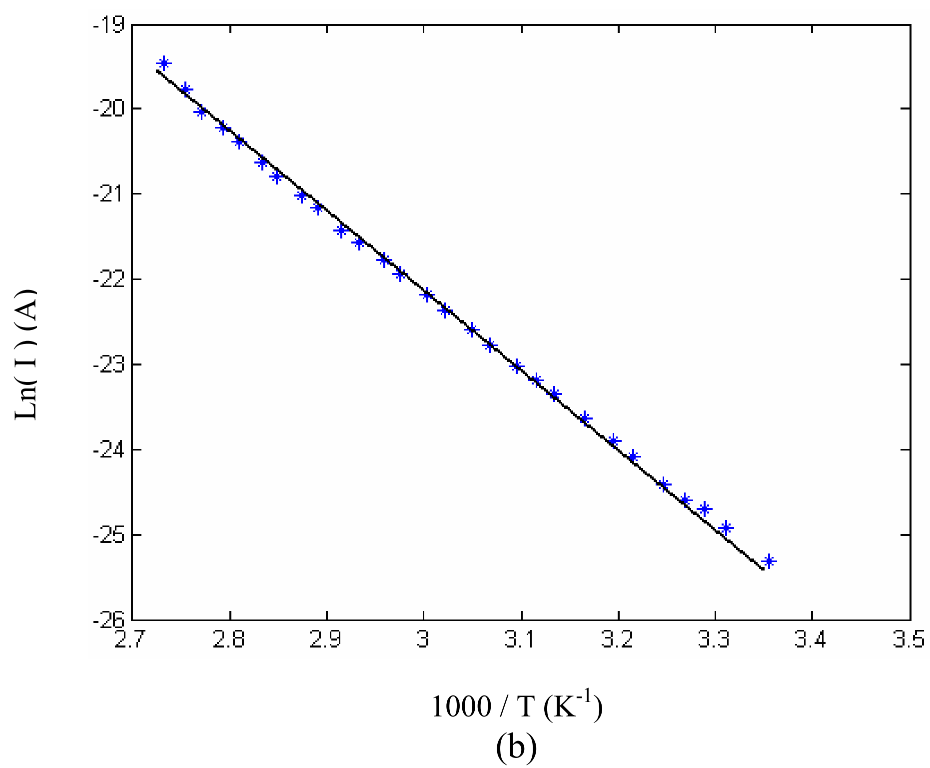


Figure (4.23): Log(σ)(Ω^{-1}) versus 1000/ T (K^{-1}) for 300, 530,800, and1100 nm Se thin film on glass .

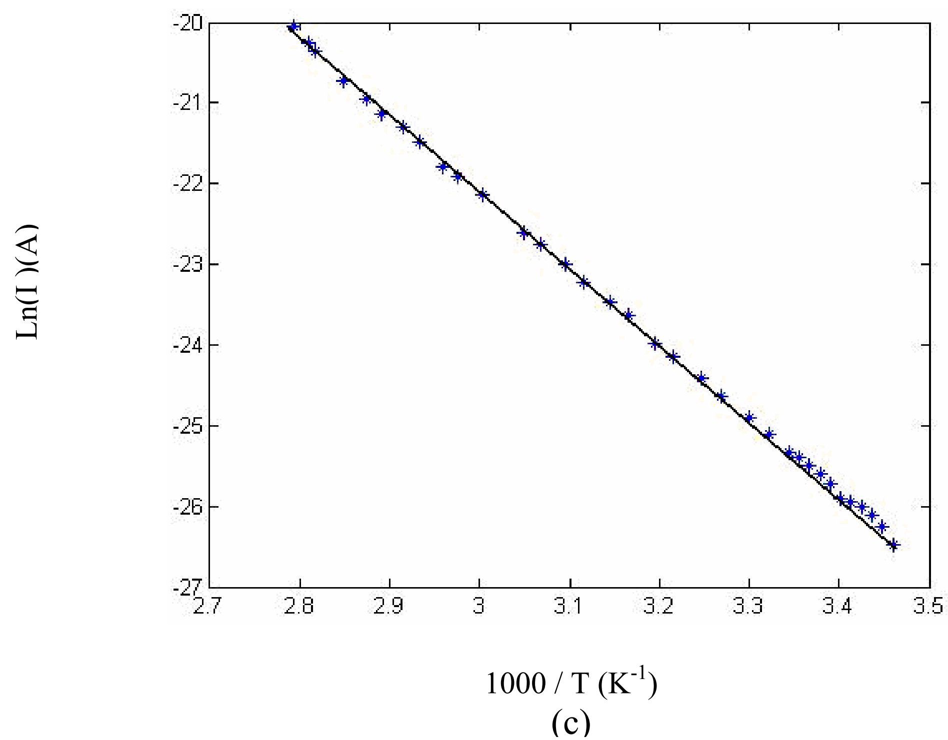
the film conductivity is increasing as temperature increases for the four films. Moreover, it is clear that Log (σ) increases with film thickness decreasing, as we expect and as was approved by a previous results [11,16]. Since the logarithmic curve shows a linear behavior of the conductivity, then we expect that Mott's model is a suitable one to explain and calculate the results of this behavior. Therefore using Eq. (2.41), if we find the linear fit of our data in Fig. (4.23) we calculate the activation energy (E_a) of each film. The calculated values of E_a are given in table (4.2) .


-19
-20
-21
-22
-23
-24
-25
-26
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
Ln(I) (A)
1000 / T (K-1)

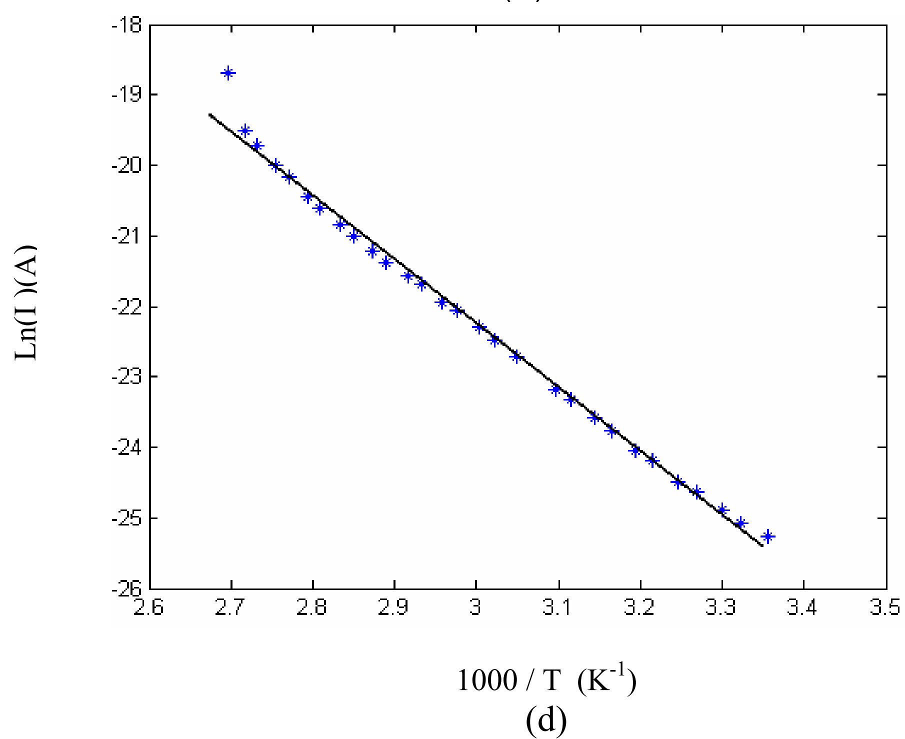
(a)


-19
-20
-21
-22
-23
-24
-25
-26
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
Ln(I) (A)
1000 / T (K-1)

(b)



(c)



(d)

Figure(4.24): a, b, c and d are Ln(I)(A) versus 1000 / T (k^{-1}) plot for 300, 530, 800, 1100nm Se thin films respectively.

Table(4.3)

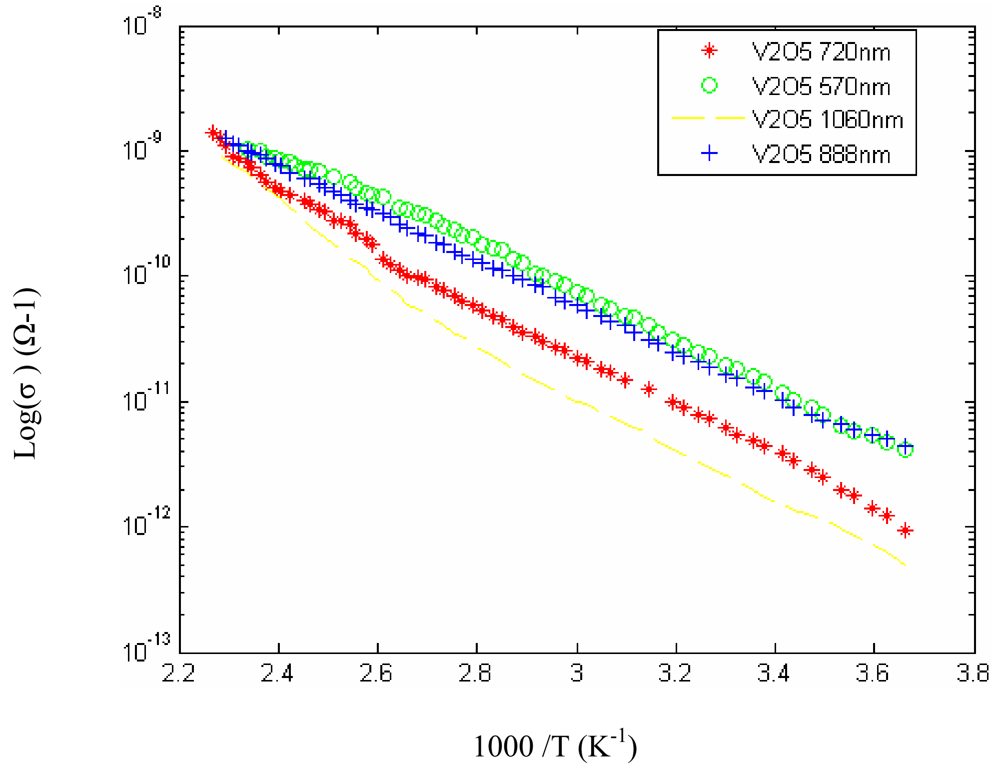
Activation energy for 300,530,800,1100nm Se thin films .

Sample thickness (nm)	E_a(ev)
Se 300nm	0.777 (T >297 K)
Se 530nm	0.78 (T >297 K)
Se 800nm	0.79 (T >297 K)
Se 1100nm	0.74 (T >297 K)

Where for all these figures the data were fitted for a,b,c and d and gives the formulas, $\ln(I) = \frac{-9000}{T} + 4.7$, $\ln(I) = \frac{-9000}{T} + 4.81$, $\ln(I) = \frac{-9200}{T} + 5.66$ and $\ln(I) = \frac{-8600}{T} + 3.58$, respectively.

4.4 Electrical properties of V_2O_5 thin films

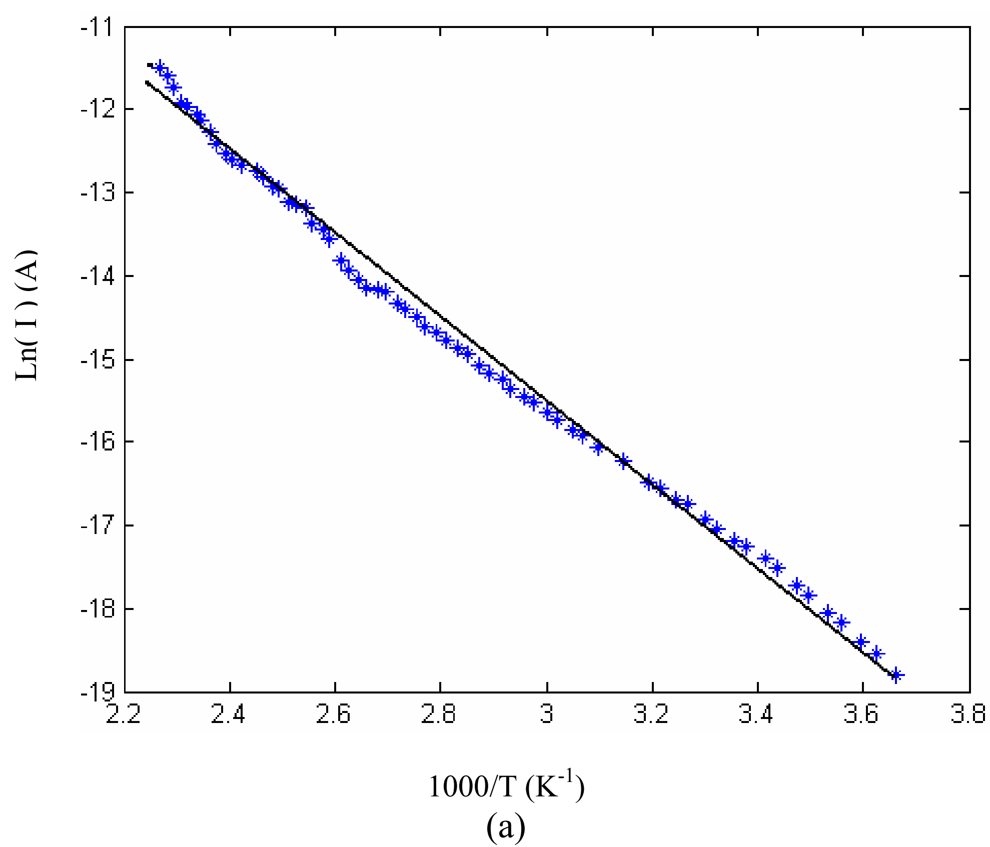
Fig. (4.25) represents the results of the measurements of the electrical conductivity for four V_2O_5 thin films. It shows how the conductivity of these films changes with temperature. Exactly we plot Log(σ) (Ω^{-1}) versus 1000 / T (K^{-1}) in order to see if Mott's model is applied for these films. It is clear that the linear behavior encourage to adopt Mott's model for finding the activation energy of each film.



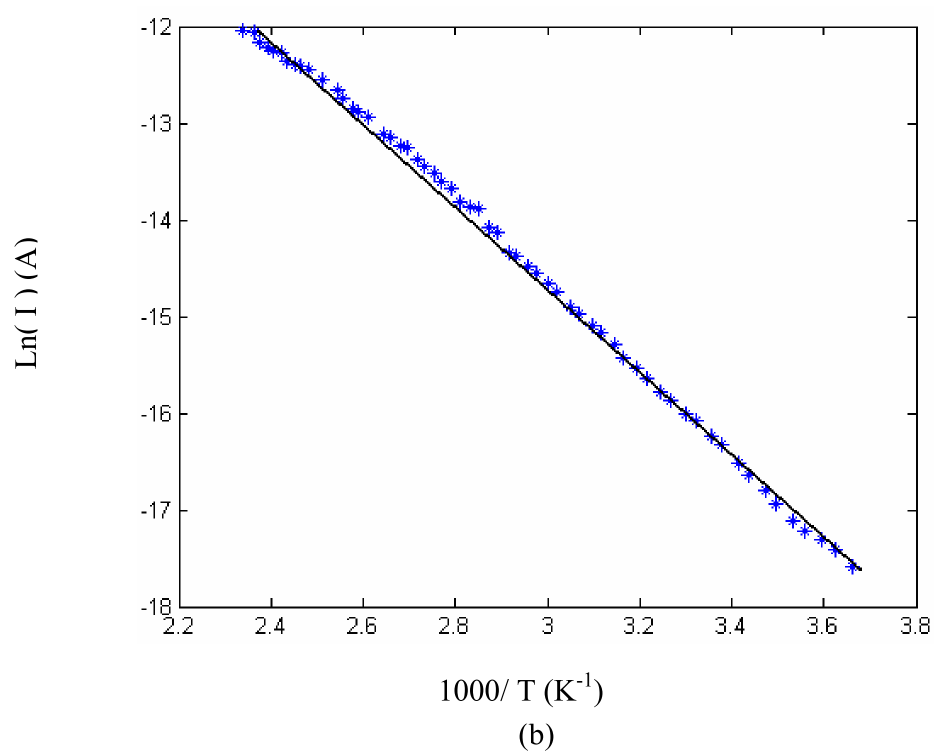
Figure(4.25): Log(σ)(Ω^{-1}) versus 1000/ T (K^{-1}) for 570, 720, 888, and1060 nm V_2O_5 thin film on glass

Also, it is clear that the film conductivity increases with increasing temperature for all films as shown in the Figure. However, at a certain temperature, the conductivity decreases with thickness with some irregular behavior in this case, especially for the films of thickness 720 nm and 888 nm. The irregularity can be explained by the fact that at low thicknesses films had become uniform and more or less like single crystal film, which is quite contradictory to the existing general observation and theories of film growth structure on amorphous substrate [16].

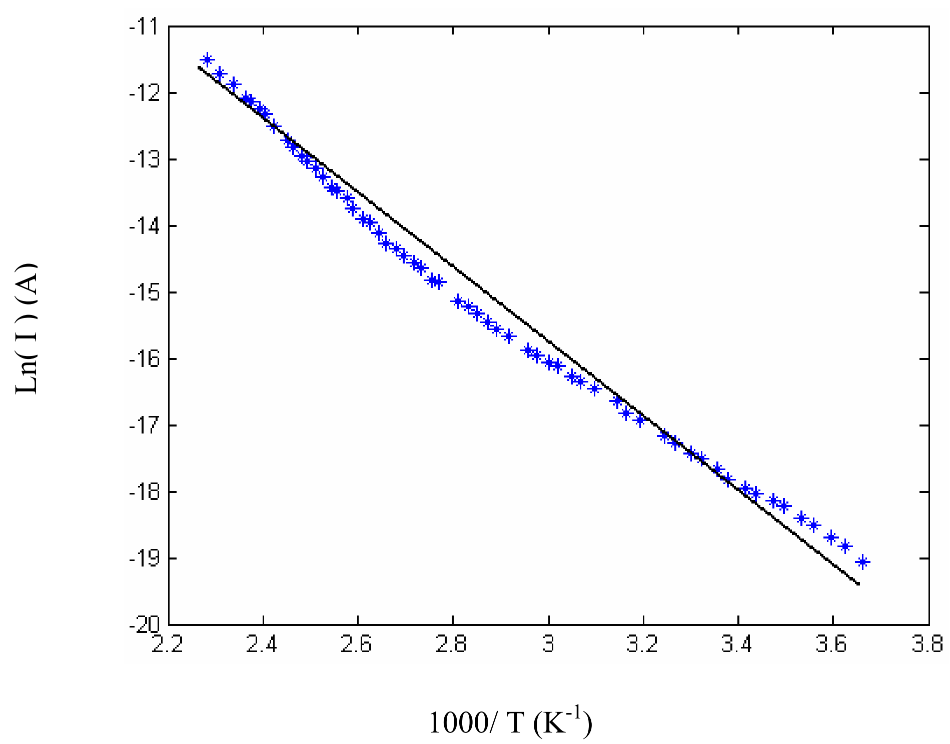
Now, fitting the experimental data to the law in the form eq. (2.41), values of E_a were evaluated from the plot of Ln(I) versus 1000/T (Fig 4.26) a,b,c, and d. where I is the current were the current is proportional to the conductivity, and the value of E_a are given in table (4.4) [10,11,15].


Ln(I) (A)
-11
-12
-13
-14
-15
-16
-17
-18
-19
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
1000/T (K^{-1})

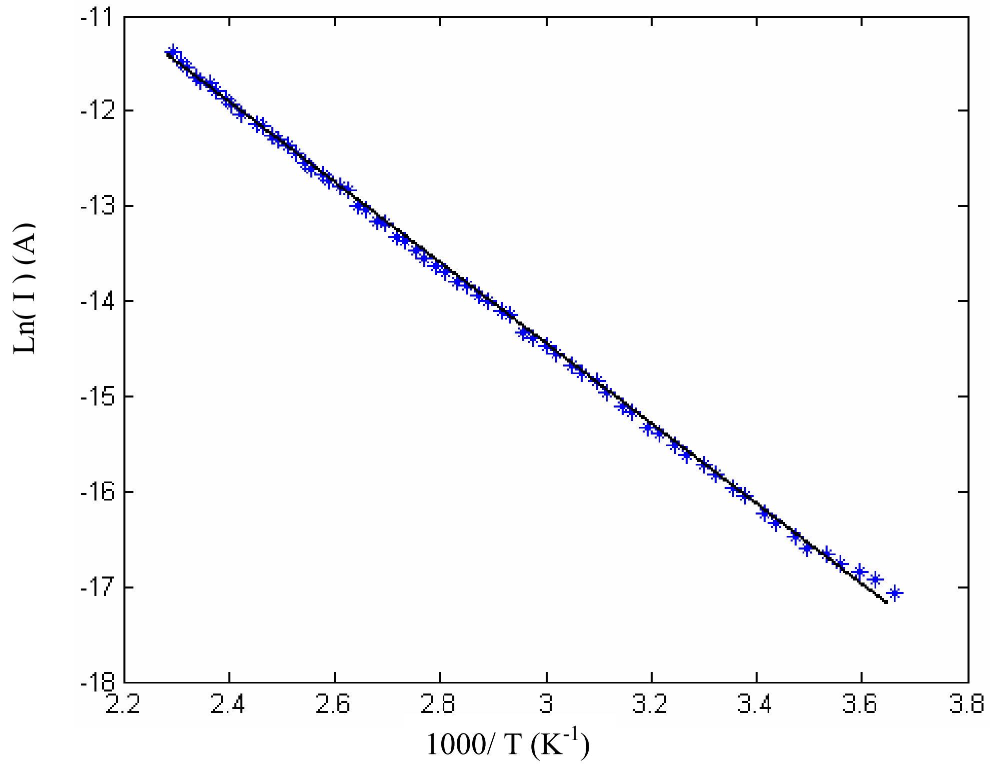
(a)


Ln(I) (A)
-12
-13
-14
-15
-16
-17
-18
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
1000/ T (K^{-1})

(b)



(c)



(d)

Figure(4.26): a, b, c and d are Ln(I)(A) versus 1000 / T (k^{-1}) plot for 720, 570, 1060, 888 nm V_2O_5 thin films respectively.

Table(4.4)

Activation energy for 570,720, 888 ,1060 nm V_2O_5 thin films .

Sample thickness (nm)	E_a(ev)
V_2O_5 570 nm	0.38 (T >271 K)
V_2O_5 720 nm	0.44 (T >271 K)
V_2O_5 888 nm	0.37 (T >271 K)
V_2O_5 1060 nm	0.46 (T >271 K)

For figure (4.26 a,b,c and d) the data were fitted and we get the following equations , $\ln(I)=\frac{-5050}{T}-0.38$, $\ln(I)=\frac{-4300}{T}-1.78$, $\ln(I)=\frac{-5400}{T}+0.46$ and $\ln(I)=\frac{-4150}{T}-2.04$, respectively .

Conclusions

In our work the electrical and optical properties for films were determined and it were founded to be as follow

1- For Selenium film with thickness 1580 nm the refractive index decreases from 2.815 to 2.615 as λ increases from 632 to 890 nm, and for film with thickness 1400 nm refractive index decreases from 2.8 to 2.58 as wavelength increases from 628.57 nm to 865.71 nm , and the absorption coefficient decreases from 0.00024712 to 0.00000379 $(cm*10^{-7})^{-1}$ as wavelength increases from 632 to 890 nm for 1580 nm film and for 1400nm it decreases from 0.000328 to 0.00000043 nm^{-1} as wavelength increases
from 628 nm to 865 nm, the extinction coefficient for 1580 nm decreases from 0.01243 to 0.000026816 as wavelength increases from 632 to 890 nm , and for 1400 nm the extinction coefficient decreases from 0.01641 to 0.00003 as wavelength increases from 628 nm to 865 nm , the energy gap was founded for Se and it was about 1.8 ev .

2- For Vanadium pentoxide film with thickness 320 nm the refractive index decreases from 1.88 to 1.73 as wavelength increases from 500 nm to 900 nm and the absorption coefficient decreases from 0.0013 nm-1 to 0.0007 nm-1 in the range of 500 nm to 620 nm. After this value of wavelength it becomes almost constant and equals to about 0.0007 nm-1, from 620 to 900 nm, and The extinction coefficient for this film decreases from 0.057 to about 0.039 as wavelength increase from 500 nm to 640 nm. Then up to 900 nm the extinction coefficient will be constant and have the value of about 0.039 .
For another film with thickness 700nm shows the refractive index variation versus wavelength where it decreases from 1.94 to1.7 as wavelength increases from 520 nm to 900 nm and the absorption coefficient decreases from 0.0009666 to 0.00035nm-1 as wavelength increases from 520 nm to 700 nm then it will be constant and equal to 0.00035 nm-1 in the interval of wavelength from 700 nm to 900 nm and the extinction coefficient decreases from 0.035 to 0.018 as wavelength increase from 500 nm to 900 nm, the energy gap was determined for V_2O_5 films and was about 1.9 ev.

3- For Se and V2O5 films the electrical properties were studied and for these films the electrical conductivity were studied with effect of thickness and temperature where the electrical conductivity increased with temperature increasing an decreased with thickness increasing , finally the activation energy for these films were determined and were it founded it be

Sample thickness (nm)	E_a(ev)
Se 300nm	0.777 (T >297 K)
Se 530nm	0.78 (T >297 K)
Se 800nm	0.79 (T >297 K)
Se 1100nm	0.74 (T >297 K)

And

Sample thickness (nm)	E_a(ev)
V_2O_5 570 nm	0.38 (T >271 K)
V_2O_5 720 nm	0.44 (T >271 K)
V_2O_5 888 nm	0.37 (T >271 K)
V_2O_5 1060 nm	0.46 (T >271 K)

4-Films with height absorption have height electrical conductivity.

References

[1] Heavens, O. S. 1991. "**Optical properties of thin films**". dover publications, New York.

[2] Wagner .T. 1985"**Thin Film Science**". Max-Planck-Institute Fur Metallforschung. 70174 Stuttgart, Germany.

[3] Swanepoel. R. 1983. "Determination of the thickness and Optical constants of Amorphous silicon". **J. Phys. E:Sci. Instrum**., Vol. 16,.

[4] Marquez. E, Ramfrez-Malo. J, Villares. P, Jimenez-Garay. R, Ewen P J S and Owen. A E. (1992) "Calculation of the thickness and Optical constant of amorphous Arsenic Sulphide films from their transmission spectra**". J. Phys. D:Appl. Phys**. 25535-541.

[5] Buch. Kranse,1997 "**Thin films on glass**",Springer.

[6] Lakatos A. I. and Abkowitz. M. 1971. "Electical Properties of Amorphous Se, As_2Se_3 , and As_2S_3". **Physical Review B**, third series, Vol. 3, No. 6, , pp. 1791 – 1800.

[7] Enck R. C. 1973. "Two Photogeneration in Amorphous Selenium". **Physical Review Letters**, Vol. 31, No. 4, , pp. 220 – 223.

[8] Vautier.C. and Viger. C.1979. "Influence of Wavelength on the Optial Quenching of Photoconductivity in Amorphous Selenium Films". **The Physics of Selenium and Tellurium Special report**, France pp. 222-224.

[9] Mehra. R. M. Henant Kumar, Surinder Koul, and Mathur. P. C. (1984), "Thickness Dependance of DC Conductivity of Amorphous Se and binary Amorphous Se-Te, Se-Ge, and Se-Sb Films",**Phys. Stat. Sol. (a),** 83, 341

[10] Larmagnac J. P., Carles D. and Lefrancois.G. (1985). "Dark Conductivity below and Above T_g in *a-Se*". **journal of Non-Crystalline Solids** 77 & 78 1237 – 1240.

[11] Qamhieh N, Willekens J, Brinza M and Adriaenssens G J. (2003) . "Anomalous DC dark Conductivity Behavior in *a-Se* films". **J. Phys.: Condens. Matter** 15L631-L635.

[12] Chavez-Rivas F., Ribeyron A. and Laurant J. M. (1982). "Optical Absorption in the low Frequency Range of Amorphous Polymeric Systems: amorphous selenium and Polymethylmethacrylate". **Physica109 and 110B.** 2119– 2121.

[13] Mehra R. M., Henant Kumar, Surinder Koul, and Mathur P. C. (1984).. "Thickness Dependance of DC Conductivity of Amorphous Se and binary Amorphous Se-Te, Se-Ge, and Se-Sb Films". **Phys. Stat. Sol. (a),** 83, 341.

[14] Salwan K. J. Al-Ani, Mehadi N. Al-Delaimi, Ali H. Abdul Munaim and Habiba M. Jawher. (1990). “Optical and Electrical Properties of pure and Doped Amorphous thin Selenium Films”. **INT. J. Electronics**, Vol. 69, NO. 1, 87-95.
[15] Grenet. J, Carles. D, Lefrancois. G. and Larmagnac. J.P. (1983). “Evidence for a Diffusion of Photo – Induced Defects In *α-Se*”. **Journal of Non-Crystalline Solids** 56285-290.
[16] Carles. D., Lefrancois. G. and Larmagnace. J. P. (1984). “A model for Steady-State Photoconductivity in Amorphous Selenium”. **J. Physique Lett**. 45L-901-L-906.
[17] Grenet. J., Carles. D., Lefrancois .G. and Larmagnac. J.P. (1983). “Evidence for a Diffusion of Photo – Induced Defects In *α-Se*”. **Journal of Non-Crystalline Solids** 56285-290.
[18] Wee Chong Tan Saskatoon, Saskatchewan,2006. “**Optical Properties of Amorphous Selenium Films**” unpublished Msc, University of Saskatchewan Library Electronic Theses & Dissertations.
[19] Bindu .K., Sudha Kartha. C., Vijayakumar .K. P, Abe, Y. Kashiwaba. (2002) . “Structural, Optical and electrical Properties of In_2Se_3 thin films formed by Annealing Chemically Deposited *Se* and Vacuum Evaporated *In* stack layers”. **Applied surface Science**, 191138-147.
[20] Bhadra .S. K, Maiti. A. K. , Goswami. K. (1999). “Photo-Darkening in *GeSe* film by CW laser Irradiation”. **Journal of Materials Science Letters**. 181543-1545.
[21] Guesdon .J. P, Kobbr. B, Julien. C, and Baekanskr. M. (1987),. “Electrical and Photovoltaic Properties of In_xSe_{1-x} Thin film”. **Phys. Stat.** Sol.(a) 102, 327Subject classification: 72.40 and 73.60 ; s4.
[22] Mehra. R. M, Mathur. P. C, Kathurla. A. K., and Radhey shyam. (1977).“Dependance of Conductivity and Activation Energy on Tellurium Concentration in Amorphous Selenium”. **Phys. Stat. Sol. (a)** 41, K189Subject Classification: 2 and 14,3; 22.1.3.
[23] Gross. G, Stephens. R. B., and D. Turnbull .1977. “On the Crystallization of Amorphous Selenium films: Thermal effects and Photo effects”. **Journal of Applied Physics** Vol 48(3) pp. 1139-1148.
[24] Hanlon. T. J, Walker. R. E., Coath. J. A., M.A. Richardson. (2002). “Comparison between Vanadium dioxide coating on glass produced by sputtering, alkoxide and aqueous sol-gel methods”. **Thin Solid Films** 405234-237.

[25] Pergament. A. L, Kazakova. E. L and Stefanovich. G. B. (2002) . "Optical and Electrical Properties of Vanadium Pentoxide Xerogel films: modification in electric field and the role of ion transport". **J. Phys. D: appl. Phys**. 352187-2197.
[26] al-Kuhaili. M. F, Khawaja. E. E, Ingram. D. C, S. Durrani. M. A. (2004) . "A Study of thin films V_2O_5 containing Molybdenum from an evaporation boat ". **Thin Solid Films**, 46030-35.
[27] Jian Meng. Li, Rui A. Silva, Hain-Ning Cui, Vasco Teixeira, Dos Santos. M. P., Zheng Xu. (2006). "Optical and Electrical Properties of Vanadium pentoxide films prepared by d . c. reactive magnetron sputtering". **Thin Film Solid**, 515195-200.
[28] Alaa A. Aki. (2007) . "Crystallization and Electrical Properties of V2O5 thin films prepared by RF sputtering". **Applied Surface Science** 2537094-7099.
[29] Putrolaynen .V. V, Velichko. A. A, A L Pergament, Cheremisin. A. B and Grishin. A. M. (2007). "UV patterning of Vanadium Pentoxide films for device applications". **J. Phys. D: Appl. Phys**. 405283-5286.
[30] Nehad Tashtoush, Ali M. Qudah, M. M. El-Desoky. 2007 . "Compositional dependence of the electrical conductivity of Calcium Vanadate glassy semiconductors". **Journal of Physics and Chemistry of Solids**, 681926-1932
[31] Zhongchun Wang, Jiefeng Chen, Xingfang Hu, 2000."Electrochromic properties of aqueous sol-gel derived Vanadium oxide films with different thicknesses". **Thin Solid Films** 375 ,238-241.
[32] Rajendra Kumar, R. T, Karunagaran. B, Senthil Kumar. V, Jeyachandran .Y. L, Mangalaraj. D, Narayandass. Sa. K.2003,"Structural properties of V_2O_5 thin films prepared by vacuum evaporation". **Materials Science in semiconductor processing**,Volume 6,Issues 5-6,page543-546.
[33] Rajendra Kumar. R. T, Karunagaran .B, Mangalaraj .D, Narayandass .Sa. K, Manoravi. P, Joseph. M, 2003. "Properties of pulsed laser deposited Vanadium Oxide thin film thermistor". **Materials Science in semiconductor processing,**Volume 6, Issues 5-6 Pages 375-377.
[34] Jacques Livage, 1999. "Optical and electrical properties of Vanadium Oxides synthesized from alkoxides". **Coordination Chemistry Reviews** 190-192 391- 403.
[35] Bhattacharya. S, Ghosh. A, 2003. "Conductivity relaxation in some fast ion-conducting $AgI\text{-}Ag_2O\text{-}V_2O_5$ glasses",**Solid State Ionics** 161, 61-65.

[36] Hanlon .T. J, Coath. J. A, Richardson. M. A, 2003. “Molybdenum-doped Vanadium dioxide coatings on glass produced by the aqueous sol-gel method”, **Thin Solid Films,** 436, 269-272.
[37] El Mandouh. Z. S, Selim. M. S, 2000. “Physical properties of vanadium pentoxide sol gel films”, **Thin Solid Films,** 371, 259-263.
[38] Sen .S and Ghosh. A, 2005. “Semiconducting properties of magnesium vanadate glasses”. **Journal of Applied Physics**, Volume 86. Number4.
[39] Bahgat. A. A, . Ibrahim. F. A, El-Desoky. M. M,2005. “Electrical and Optical properties of highly oriented nanocrystalline Vanadium Pentoxide”. **Thin Solid Films**,Volume 489,Issues1-2,Pages 68-73.
[40] Manifacier. J. C, Gasiot. J and Fillard. J. P, 1976. “A simple method for the determination of the optical constant n,k and the thickness of a weakly absorbing film”, **J. Phys. E: Sci**. Instrum. 9, 1002.
[41] Bindu. K, Sudha Kartha .C, Vijayakumar. K. P, Abe. Kashiwaba. T,2002 ,“Structural ,optical and electrical properties of In_2Se_3 thin films formed by annealing chemically deposited Se and vacuum evaporated In stack layers”,**Applied Surface Science**, Volume 191,Issues1-4,Pages 138-147.
[42] Streetman. Ben. G.1990, “**Solid state electronic devices**”, Prentice-Hall, Englewood cliffs, 3 rd edition .

المعلومات الشخصية

الاسم :- اسامه محمد سلمان الكساسبه .

الكلية :- العلوم .

التخصص :- الفيزياء .

السنة :- 2010

الهاتف النقال :- 0777169258

البريد الالكتروني :- osaphy@yahoo.com